A Review of

The NRCE (2002) Report Entitled

"Assessment of Imperial Irrigation District's Water Use"

Prepared by
The Water Advisory Committee
for the
Coachella Valley Water District

May, 2003

A REVIEW OF THE NRCE (2002) REPORT ENTITLED "ASSESSMENT OF IMPERIAL IRRIGATION DISTRICT'S WATER USE"

I. INTRODUCTION

A. Water Advisory Committee for CVWD (WAC)

The Coachella Valley Water District (CVWD) established the WAC in 1996 to assist the District in analyzing past and current agricultural water use and management within the Imperial Irrigation District. In addition and at the direction of the CVWD, the committee (WAC) has assessed the opportunities for future improvements in water use in IID. The WAC team currently consists of:

Dr. James R. Gilley, Agricultural Engineer, Professor, Biological and Agricultural Engineering Department, Texas A and M University, College Station, Texas;

Dr. Robert W. Hill, Irrigation Engineer, Professor and Extension Specialist, Biological and Irrigation Engineering Department, Utah State University, Logan, Utah;

Mr. Joseph M. Lord, Jr., P.E., President JMLord, Inc, Fresno, California (WAC Chair);

Dr. Charles V. Moore, Senior Research Agricultural Economist, University of California, Davis, California;

Dr. Earl C. Stegman, Agricultural Engineer, Professor and Chair, Agricultural and Biosystems Engineering Department, North Dakota State University, Fargo, North Dakota;

Dr. Kenneth K. Tanji, Soil and Water Chemist, Professor Emeritus in Hydrology, Department of Land, Air and Water Resources, University of California, Davis, California;

Dr. Wesley W. Wallender, Agricultural Engineer, Professor, Department of Land, Air and Water Resources and Biological and Agricultural Engineering, University of California, Davis, California.

This committee reports to Mr. Gerald Shoaf, the Chief Counsel for CVWD.

The WAC team has individually and collectively reviewed and thoroughly considered many reports and publications regarding the use of water in the Imperial Irrigation District in the course of the committee's analysis. The WAC team members have also participated in team and individual field visits to the IID service area to observe conditions generally. One of the Water Advisory Committee's (WAC) primary responsibilities was to review available data and background information and analyze this information to determine the beneficial use of Colorado River water within IID. The WAC team has presented its findings and conclusions in "Water

Management within the Imperial Irrigation District," dated May 2003. This report is a review of Natural Resource Consulting Engineers, Inc. (NRCE) report "Assessment of Imperial Irrigation District's Water Use," dated March 2002.

B. Objectives of This Report

The primary purpose of this report is to provide a review, critique and rebuttal of specified areas within the NRCE report (NRCE, 2002). Due to time limitations, comments on every section of the report were not possible. The lack of comments to other areas of the subject report not mentioned in this report should not be construed as acceptance of the document statements.

The focus of this report follows:

1. Dr. Charles V. Moore, in **Section II** of this report comments on and rebuts the "Evaluation of IID Grower Market Power" by Jasson Bass and Jim Merchant, Appendix 10 of the NRCE, 2002 report. Dr. Moore proposes that the comments regarding the "ability to pay", question needs to be replaced with the question, "What is the Willingness to Pay?"

2. Comments on the water use portions of the subject report are provided by Dr. Earl C. Stegman and appear in **Section III** of this report. The comments describe the NRCE methodology and provide the NRCE equivalent results for CCUnet/Irdel (61%) and CCUnet/Irfarm Ratio (71%). The comments continue with a comparison of the NRCE results to alternative mean and time series data.

3. Comments and rebuttal on Tailwater Management within the Imperial Irrigation District are provided by Dr. James R. Gilley and appear in **Section IV** of this report. These comments provide a comparison of the tailwater results of the NRCE report with those found in the Jensen, M. E. and I. A. Walter, 2002 study and the Water Study Team, 1998 study. Analysis of previous studies of the performance of IID indicated that the estimates of tailwater runoff have increased through the years 1987 through 1997 (with the exception of the 1992/1993 fly infestation events). Next is an analysis of the tailwater runoff from individual irrigation events and fields. A discussion of the potential for tailwater reduction on the cracking clay soil in the Imperial Irrigation District is also provided. The analysis shows that tailwater can be virtually eliminated with little to no cost as indicated by the NRCE field tests. The review concludes with a presentation of issues concerning tailwater as non-beneficial use of Colorado River water.

4. Comments and rebuttal on Salinity of Soil and Water as well as Effectiveness of Tailwater Leaching is provided by Dr. Kenneth K. Tanji and Dr. Wesley W. Wallender and appear in **Section V** of this report. Comments are referenced by page, paragraph and line to the subject document. Comments cover the WATER USE, Appendix 7 of the NRCE, 2002 report, and Dr. Woldezion Mesghinna testimony.

C. Background of the Imperial Irrigation District

Imperial Irrigation District. The Imperial Valley of Southeastern California is a low desert arid climate location characterized by hot summers, mild winters, high evaporation, and low precipitation. Year round cropping and potential multiple cropping is possible with low probability of winter frosts. The hot summertime temperatures can be detrimental to crop (such as alfalfa) growth and yield.

The diversion and use irrigation water throughout the year from the Colorado River, at Imperial Dam, are essential to maintain a viable agricultural economy of between 440,000 and 468,000 irrigated acres (1972-2000). Total cropped area, including double crop, has varied from about 500,000 to 610,000 acres during the same time period. Field crops have dominated in IID, being about 80 percent of the area with the remainder in garden crops. Alfalfa and wheat are the dominant field crops, whereas lettuce and melons are the major vegetables.

Diversions of Colorado River water to the IID service area occur through the All-American Canal from Imperial Dam and are measured at Drop One. Water delivery volumes into the Imperial Irrigation District, measured at Drop One, have fluctuated from 2.4 to over 3.1 million-acre feet during the period 1972 – 2000 (**Figure 1**). As seen in **Figure 1**, the diversions to IID, as measured in the All American Canal at Drop One have generally increased between 1983 and 2000 and have risen from a low of approximately 2.4 million acre-feet per year to levels exceeding 3.1 million acre feet per year in 1996. The diversions per acre of crop land are also shown in **Figure 1.** Deliveries to IID have risen from a level of approximately 4.6 acre-feet /acre in the early 1980's to a level approaching 5.7 acre-feet/acre in 2000. These increases can not be substantiated based upon increases in double cropping, changes in crop mix, changes in weather patterns nor changes in Colorado River water salinity (WAC, 2003). Water deliveries in 1992 and 1993 were abnormally low because of a white fly infestation on alfalfa and producers reduced their water applications on alfalfa.

Water management within the Imperial Irrigation System is unique in that irrigation return flows do not return to their source, the Colorado River. These flows from the irrigated lands in the Imperial Irrigation District flow to the Salton Sea. Thus, in order for conservation measures and improvements in both farm and district operating practices to impact Colorado River supplies, the diversions to the Imperial Irrigation District at the start of the All American Canal must be reduced in proportion to the quantities of water conserved. Irrigation flows returning to the Salton Sea from the Imperial Irrigation District are shown in **Figure 2**. The magnitude of the irrigation flows to the Salton Sea have increased from approximately 850,000 acre-feet in 1987 (32% of diversions measured at EHL) to nearly 1.1 million acre-feet in 1995 (36.5% of diversions measured at EHL).

Analyses Of Water Use Assessment Within IID. Historically, there has been much concern on the effectiveness of Colorado River water use by the Imperial Irrigation District, and there have been a number of reports examining this question over the years. These evaluations represent a progression in awareness and analysis of the complex technical issues involved in determining beneficial use on a district wide scale. This report summarizes and compares the results of these previous reports and provides general conclusions supported by each of the previous reports regarding the beneficial use of Colorado River water within the Imperial Irrigation District. Particular emphasis is placed on the recent report by the Natural Resources Consulting Report (NRCE, 2002). The reports compared are:

> The Technical Work Group (TWG) report, “Water Use Assessment: Coachella Valley Water District and Imperial Irrigation District, Phase I Report” was prepared in 1994. This report reviewed existing data, made estimates of irrigation water volumes consumed or used for crop growth or salt removal, and assigned confidence intervals to water use component volumes. The TWG used a combination of water balance and climate-based evapotranspiration (ET) calculation techniques to estimate the volume of irrigation water used within the irrigation districts for crop growth and salt removal.
>
> The Jensen report entitled “Water Use Assessment of the Imperial Irrigation District” was released in 1995. A climate-based ET calculation with certain components adjusted based on yield-ET relationships and water balances were used to obtain estimates of water losses. This report was updated in 1997 by Jensen and Walter (1997), “Assessment of 1987-1996 Water Use by the Imperial Irrigation District using Water Balance and Cropping Data.” These reports were prepared for the U.S. Bureau of Reclamation. The report was updated in 2002 by the Jensen and Walter (2002), “Assessment of the 1997-2001 Water Use by the Imperial Irrigation District.”
>
> The Water Study Team (WST) commissioned by the Imperial Irrigation District, prepared a report “Imperial Irrigation District Water Use Assessment for the Years 1987-1996.” The report utilized a water balance along with calculations of crop evapotranspiration (ET) for the irrigated land within the Imperial Valley. This report used the same basic climatic data as the Jensen and Walter reports.
>
> The NRCE report commissioned by the Imperial Irrigation District and titled “Assessment of Imperial Irrigation District’s Water Use.” This report was released in March 2002 and utilizes the same procedures developed by the WST for the 1988-1997 time period.
>
> The WAC report commissioned by the Coachella Valley Water District and titled “Water Management within the Imperial Irrigation District.” This report was released in May 2003 and includes further review and analysis of available IID data for a longer time series than reported by Jensen and Walter (1997). The report also provides quantification of district wide water use, irrigation performance measures, and salinity management using water and salinity budgets.

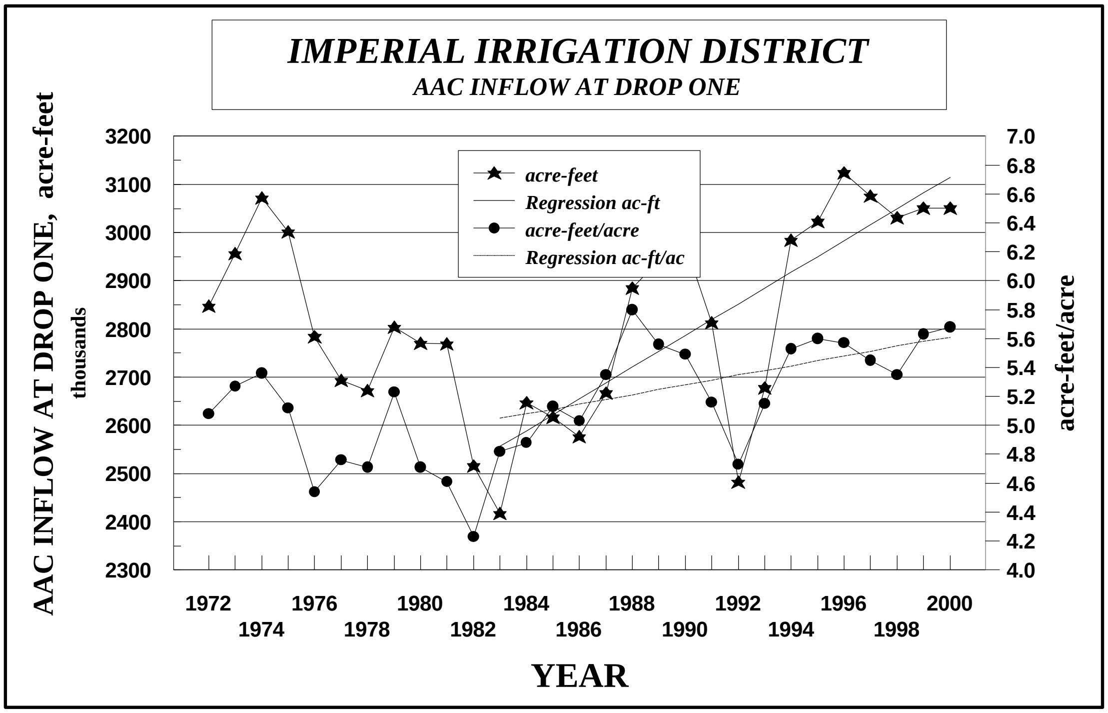

Figure 1. Inflow into the All American Canal, measured at Drop one. Data from the WAC report.

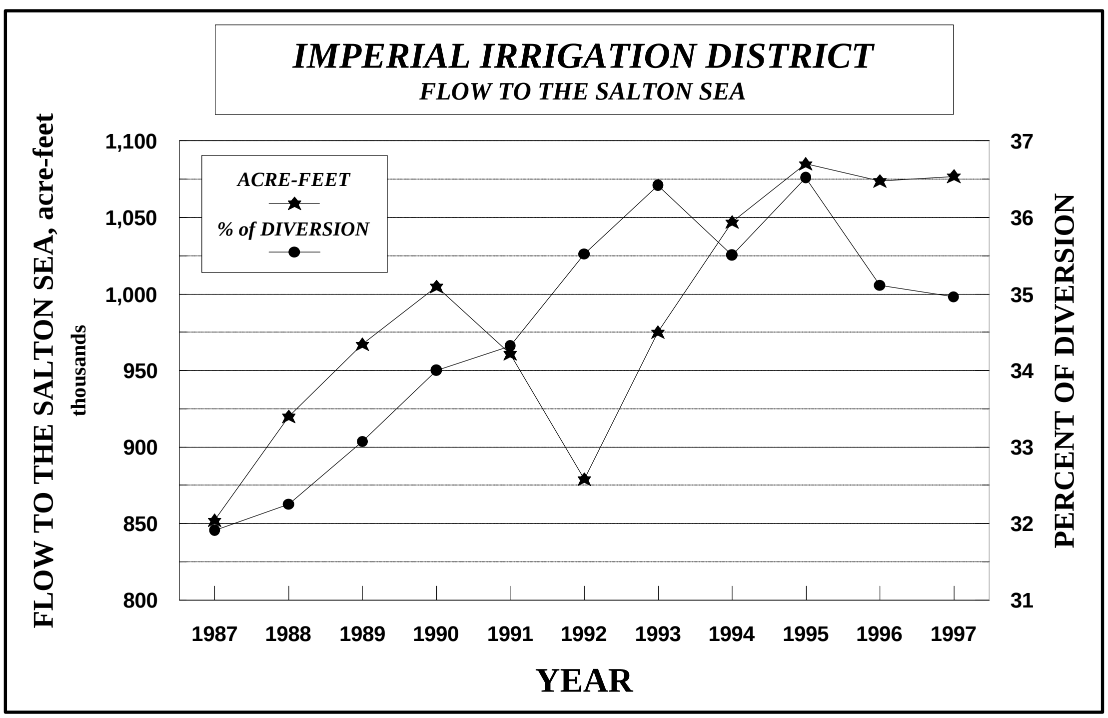

Figure 2. Flows of irrigation water from the Imperial Irrigation District to the Salton Sea. Flows are given in both thousands of acre-feet and as a percent of diversions to IID.

II. COMMENTS OF DR. CHARLES V. MOORE: COST IMPACT

Agricultural production and marketing worldwide is characterized as many buyers and many sellers including the commodities produced in IID. By definition, this can be described as, "pure competition". To pursue the argument in Appendix 10 of the NRCE report (NRCE, 2002), the section "Inability of IID growers to pass through water rate increases", asks the wrong question.

The "ability to pay", question should be replaced with the question, "What is the Willingness to Pay of IID growers, given the high probability that their water supply will be reduced in the near future?"

"Willingness to Pay" for water conservation is based on the desire of a farm operator or landowner in IID to remain in business in the long run. That is, how much are the directly affected parties willing to invest to protect their future stream of agricultural income?

As noted elsewhere, IID growers and landowners have a wide range of water conserving technologies from which to choose. These technologies range from simply adding a second irrigator in the field using the "cutback method" of irrigation, or the installation of tailwater reuse systems, which have a wide range in cost between $25 and $75 per acre foot of water saved.

The US Census of Agriculture reports that approximately 70 percent of the crop land in Imperial County is operated by tenants, i.e., owned by absentee landlords. Many of the landlords live in the coastal area of Southern California and are paid and annual cash rent per acre. Rents are related to soil quality and productivity. That is, light textured soils capable of producing winter vegetables and high yields of field crops rent for a higher rate than the heavy textured clay soils with limited adoptability and yields.

Thus, if IID farm operators wish to protect their investments in land, land leases and machinery, they must behave as prudent investors and cease wasting Colorado River water. An analogy would be an apartment owner who discovers termites in his/her buildings. It is not a question of, "Ability to Pay", but a question of "Willingness to Pay" to preserve and protect an economic asset and the stream of income generated by that asset.

Farm owner/operators will be impacted by this investment to preserve their most valuable asset but adding a second irrigator in the field would be cost effective and increase the incomes of farm workers in the Valley. The income multiplier effect on the economies of cities and towns in the Imperial Valley would be significant.

Absentee landowners would probably observe lower cash rent offers to compensate tenant operators who hire additional irrigators or install portable pump back tailwater systems on rented land, thereby reducing the present value of the irrigated land in the valley. The economic impact of this water saving requirement would be to keep more money in the Imperial Valley and reduce the cash outflow to the Greater Los Angeles/ San Diego areas of the State.

III. COMMENTS OF DR. EARL C. STEGMAN: IRRIGATION WATER USE IN IID

A. NRCE's Annual Volume of Net Crop Consumptive use in IID

The methods of net crop consumptive use computation by the NRCE (2002 Report) are reviewed and compared to other reports as follows.

NRCE selected the FAO Penman-Monteith (FAO P-M) equation as presented in the FAO Irrigation and Drainage Paper #56 (Allen et al., 1998) to estimate reference evapotranspiration (ETo). Three CIMIS weather stations in the Imperial Valley were used as sources for the weather parameters required to estimate daily ETo.

The methodology of Kc crop coefficients was followed as outlined in the FAO-56 to estimate crop evapotranspiration, ETc. Crop coefficient curves were developed for most field, garden, and permanent crops, each curve consisting of four straight lines developed to model the four major growth stages in a specific crop. The crop coefficients (Kc) were adjusted for conditions in IID (NRCE Report, 2002). Guidelines, as described in the FAO-56, were used for adjusting standard Kc values for weather factors (wind speed, relative humidity) and crop height. The initial segments of Kc curves were also adjusted to reflect effects of cultivation and irrigation management practices (i.e., prevailing special irrigation practices for crops in IID before planting and during the initial stage of growth).

Crop acreages, growing seasons (planting and harvest dates) etc. were developed for 31 major crop categories (10 in field crops, 14 in garden crops, and 7 in permanent crops). The seasonal crop acreages were obtained from IID Monthly Crop Acreage Reports. Crop planting dates were estimated as the date at which 50% of the total planted acreage of an annual crop category had been planted. Similarly, the harvest dates of a crop category were determined by choosing the date at which 50% of the total crop acreage had been harvested.

Effective precipitation (Pe) was estimated by using the USDA-SCS (1985) technique.
Computationally, the ETc for each of the crop categories was determined on a daily basis using the daily ETo calculated from the FAO Penman-Monteith equation and the respective crop coefficient curves. The daily ETc estimates were summed to obtain monthly ETc values. The monthly net irrigation requirement (NIR) or Net Crop Consumptive Use (CCUnet) were computed by subtracting the monthly effective precipitation from the estimated monthly ETc. Note that the term CCUnet is numerically the same as NIR and that the term CCUnet is the net annual crop consumptive use minus the effective precipitation.

B. NRCE's Annual CCUnet, CCUnet/IRdel, and CCUnet/IRfarm

The NRCE calculations of annual CCUnet volumes for the 1988-1997 time period are summarized in **Table 1**. Included are the total annual crop acres (including double crop) and the computed average CCUnet per crop acre per year. Also listed are annual delivery volumes at

Drop One (IRdel) and annual delivery volumes to agricultural users (IRfarm); and the computed ratios of CCUnet/IRdel and CCUnet/IRfarm.

For the 1988-97 period of the NRCE's assessment of water use, the CCUnet/IRdel ratio averaged 0.61 (i.e, net crop consumptive use averaged 61% of the Drop One delivery volumes). When based on delivery volumes to agricultural users (IRfarm), CCUnet volumes averaged 70 percent of these annual volumes.

Table 1 Data and calculated parameters based on NRCE's assessment of Imperial District water use.

Assess-ment Year	Total Area of Crops	CCUnet	CCUnet per Crop Acre	Delivery at Drop1 (IRdel)	CCUnet/ IRdel Ratio	Delivery to Agr. Users (IRfarm)	CCUnet/ IRfarm Ratio
	Acres	Kaf	ac-ft/ac	Kaf		Kaf	
1988	497659	1793	3.60	2850	0.63	2475	0.72
1989	528851	1802	3.41	2922	0.62	2558	0.70
1990	541636	1807	3.34	2957	0.61	2604	0.69
1991	544645	1723	3.16	2798	0.62	2438	0.71
1992	524718	1528	2.91	2475	0.62	2098	0.73
1993	519790	1604	3.09	2675	0.60	2322	0.69
1994	539667	1771	3.28	2948	0.60	2570	0.69
1995	539504	1741	3.23	2969	0.59	2575	0.68
1996	560460	1823	3.25	3056	0.60	2709	0.67
1997	564873	1868	3.31	3067	0.61	2684	0.70
Mean	536180	1746	3.26	2872	0.61	2503	0.70

Total area of crops—Source: annual IID inventory data (1996,1997,2001)
CCUnet – net crop consumptive use based on NRCE methods for computation/estimation of ETo, ETc , and effective precipitation –Source: NRCE, Inc 2002,
Delivery at Drop 1 – Source: IID annual data
Delivery to Agr. Users –Source: NRCE, Inc 2002,

C. Comparisons of NRCE's Calculations to Alternative Data

A comparison of the NRCE results with those from four other assessments of water use in IID is given in **Table 2**. As presented in **Table 2**, the WAC assessment (2003) of CCUnet was based on the Jensen Spreadsheet Model (Jensen, 1995). The Jensen and Walter (1997) CCUnet assessment was based on the 1997 report of Jensen and Walter where calculations were mainly based on water balance data and crop acreage data. The WST CCUnet assessment was based on the 1998 report of IID's Water Study Team and calculations were also based on water balance data. The Jensen and Walter (2002) CCUnet assessment was based on the 2002 report of Jensen and Walter which was based on use of recently standardized procedures for use of the Penman-

Monteith equation and Kc crop coefficient methods as described in FAO-56 publication (Allen et al., 1998). The respective assessments (by years) for the various reports are:

Study	Years of Assessment
WAC	1972-2000
JW 97	1987-1996
JW 02	1987-2001
WST	1987-1996
NRCE	1988-1997

The mean values for all of these assessments show a high degree of consistency. The CCUnet means range from 1720 Kaf for the 29 year period in the WAC assessment to a high of 1784 Kaf for the Jensen and Walter (2002) assessment in the 1987-2001 period. The value of CCUnet per crop acre averaged 3.13 ac-ft/ac for the 29 year assessment and essentially 3.3 ac-ft/ac for each of the other shorter/recent period assessments. **The respective ratios of CCUnet/IRdel averaged identically 0.61 for all assessments. The ratio CCUnet/IRfarm similarly averaged identically 0.70 for all assessments.** Accordingly, the data presented in **Table 2** would indicate that the same results regarding the net crop consumptive use (acre-feet) the net crop consumptive use per acre-foot of water diverted (decimal)) and the net crop consumptive use per acre-foot of water delivered to agriculture users (decimal) were identical. It would follow that the losses from agricultural land (the sum of tile water and tailwater) would be similar from each of the analyses.

Table 2. Alternative Comparisons of Mean Assessment Values

Assess-Ment by	Years of Assess-ment	CCUnet	CCUnet per Crop Acre	Delivery at Drop1 (IRdel)	CCUnet/ IRdel Ratio	Delivery to Agr. Users (IRfarm)	CCUnet/ IRfarm Ratio
		Kaf	ac-ft/ac	Kaf		Kaf	
WAC	72-00	1720	3.13	2825	0.61	2451	0.70
JW 97	87-96	1737	3.28	2856	0.61	2476	0.70
JW 02	87-01	1777	3.32	2922	0.61	2535	0.70
WST	87-96	1737	3.28	2856	0.61	2466	0.70
NRCE	88-97	1746	3.26	2872	0.61	2503	0.70

WAC –Water Advisory Committee, 2003.
JW-97—Jensen and Walter, 1997.
JW 02—Jensen and Walter, 2002.
WST – Water Study Team, 1998.
NRCE – NRCE, 2002.

D. Time Series Comparisons

Time Series for CCUnet. Time series comparisons of the various assessments of crop water consumptive use are given in **Figure 3**. The annual CCUnet volumes, based on WAC water use assessment for the 1972-1990 period, averaged near 1700 Kaf. In years since 1994, the annual CCUnet volumes have averaged 1853 Kaf for 1994-2001 period (based on Jensen and Walter, 2002), 1829 Kaf for 1994-2000 (based on WAC, 2003), 1800 Kaf for 1994-1997 (based on NRCE, 2002), and 1785 Kaf for 1994-1996 (based on WST, 1998). As shown in Figure 2, there are relatively small differences in the resulting calculations on net crop consumptive use among the various reports.

Time Series for CCUnet/Crop Acre. A comparison of the net crop consumptive use per crop acre (including double crop) is shown in **Figure 4**. Annual volumes per acre averaged near 3.39 ac-ft/ac for the Jensen and Walter 2002 assessment for 1994-2001, 3.33 ac-ft/ac for WAC assessment for 1994-2000, 3.27 ac-ft/ac for NRCE assessment for1994-1997, and 3.28 ac-ft/ac for WST assessment for 1994-1996. For the 1987-1997 time period there are only relatively small differences for the net crop consumptive use per crop area, especially for the two studies commissioned by the IID, namely the WST (1998) and NRCE (2002) reports.

Time Series for CCUnet/IRdel. A comparison of the ratio of the annual net crop consumptive use (CCUnet) to associated annual delivery volumes at Drop One (IRdel) is shown in **Figure 5**. The 29 year WAC assessment indicates these ratios rose from about 0.57 in the early 1970s to highs exceeding 0.65 in the early 1980s. Subsequently, these ratios appear to have returned to lower levels. In the mid to late 1990s they were near their 29-year average of 0.61. As noted earlier (**Table 2**), the CCUnet/IRdel ratio also averaged 0.61 for each of the other assessments over the respective periods of evaluation.

The ratio of CCUnet/IRdel that are specific to the NRCE (2002) and WST (1998) reports are illustrated in **Figure 6**. These reports, respectively, illustrate very similar findings and indicate that this ratio generally declined from near 0.63 in 1987-1988 to near 0.58 in 1995. A recovery to about 0.61 in 1997 is indicated by the WST-based ratio. Again, both of these reports, WST(1998) and NRCE(2002) were commissioned by the IID.

Time Series for CCUnet/IRfarm. A comparison of the ratios of annual CCUnet to associated annual delivery volumes at Drop One (IRfarm) is shown in **Figure 7**. The 29 year WAC assessment indicates these ratios rose from about 0.67 in the early 1970s to highs exceeding 0.75 in the early 1980s. Subsequently, these ratios appear to have returned to lower levels. In the mid to late 1990s they were near their 29-year average of 0.70. As noted earlier (**Table 2**), the CCUnet/IRdel ratio also averaged 0.70 for each of the other assessments over the respective periods of evaluation.

The CCUnet/IRfarm ratios that are specific to the NRCE (2002) and WST (1998) reports are illustrated in **Figure 8**. These reports which were commissioned by the IID, illustrate very similar findings and indicate that this ratio generally declined from near 0.73 in 1987-1988 to near 0.67 in 1995. A recovery to about 0.70 in 1997 is indicated by the WST-based ratio.

Time Series for Crop Leaching Requirement Volume (LRvol. as a Ratio of IRdiv. Crop leaching requirement volumes were calculated by the WST (1998) by applying the Ayers-Westcot (1985) equation with procedures defined for heavy cracking soils involving "a leaching multiplier" and "miles of tile drainage" (WST report Table A4-11). The net effect of these procedures was equivalent to using an average threshold ECe = 1.97 in the Ayers-Westcot equation. For light or non-cracking soils (estimated to cover 50% of the district-wide CCUnet), the WST used a threshold ECe = 1.70. For these procedures and the mean salinity level of Colorado River water at Imperial Dam (ECiw = 1.16 DS/m), the WST calculations of annual crop leaching volume requirement (WST report Table A2-24) averaged 296,000 ac-ft in the 1987-1996 period. Thus, the ratio LRvol/IRdel averaged 0.10 (i.e., 296,000/2,856,000) in this ten year period.

Similarly, in the (WAC) analysis the Ayers-Westcot equation was applied to the 1972-2000 period to calculate annual crop leaching requirement volumes. These volumes averaged 292,000 ac-ft for a crop-area weighted threshold ECe = 1.85. Their calculated LRvol/IRdel ratios averaged 0.10. The annual ratios are plotted in **Figure 9**.

Time Series on Agricultural Tailwater. Annual agricultural tailwater volumes in IID were calculated as follows:

DStot = IRfarm – CCUnet

Where:

DStot = annual agricultural irrigation volume entering the drainage system (surface tailwater + tilewater volumes)

IRfarm = annual delivery to agricultural users (IID annual data)

CCUnet = net crop consumptive use, described earlier.

And:

TW = DStot - LRvol

Where:

TW = annual agricultural tailwater volume not used for leaching requirement

LRvol = leaching requirement volume, described earlier.

A comparison of the annual drainage system volumes and tailwater volumes (DStot and TW) to the annual irrigation deliveries (IRdel and IRfarm), the annual net crop consumptive use (CCUnet), and to the net annual outflow to the Salton Sea (SS) is shown in **Figure 10**.

The total irrigation water leaving farms (DStot) and tailwater volumes (TW) generally declined in the period from 1972 to the mid 1980s. Since then the DStot volumes have increased, rising to magnitudes in the 1996-2000 period that averaged 832,000 ac-ft annually (**Figure 10**). Similarly, the TW volumes not required for leaching in this period have averaged 548,000 ac-ft annually.

Comparions of the calculated annual ratios of DStot/IRfarm and TW/IRfarm are shown in **Figure 11.** These ratios, as expected, follow the same patterns as exhibited by the DStot volumes in **Figure 10**. In the 1996-2000 period, the TWtot/IRfarm ratio averaged 0.31, indicating that annual irrigation volume entering the drainage system (surface tailwater plus tilewater) averaged 31 percent of the irrigation delivery volume to agricultural users.

In the 1996-2000 period the annual TW volume not required for leaching averaged 21 percent (average ratio = 0.21) of the annual irrigation delivery volume to agricultural users (**Figure 11**).

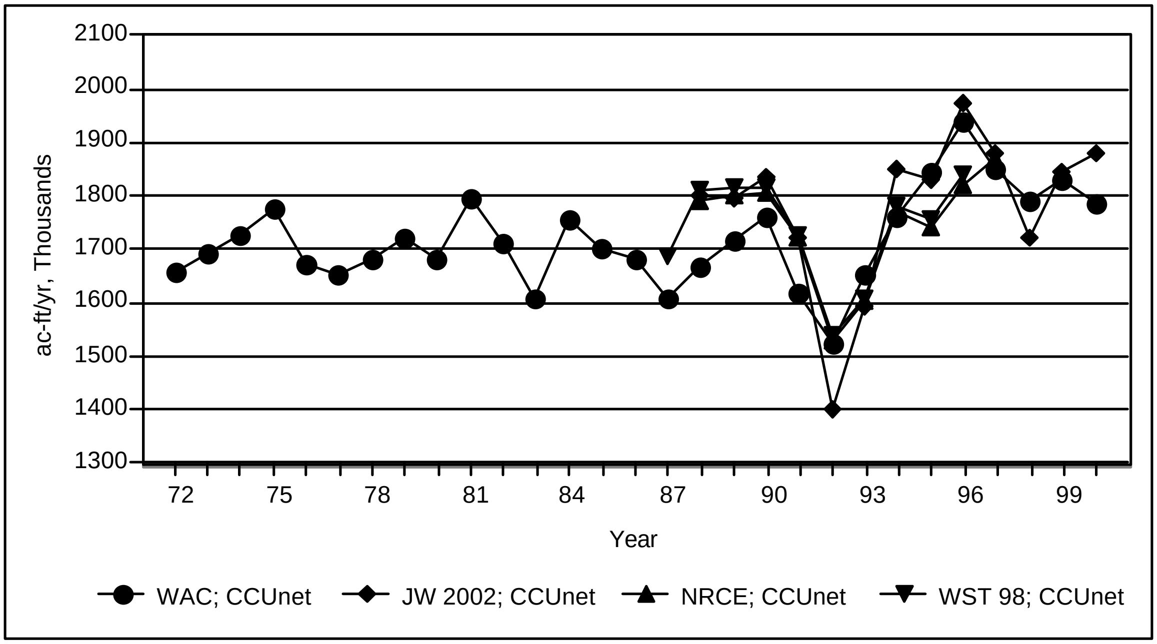

Figure 3. Annual net crop consumptive use,CCUnet.

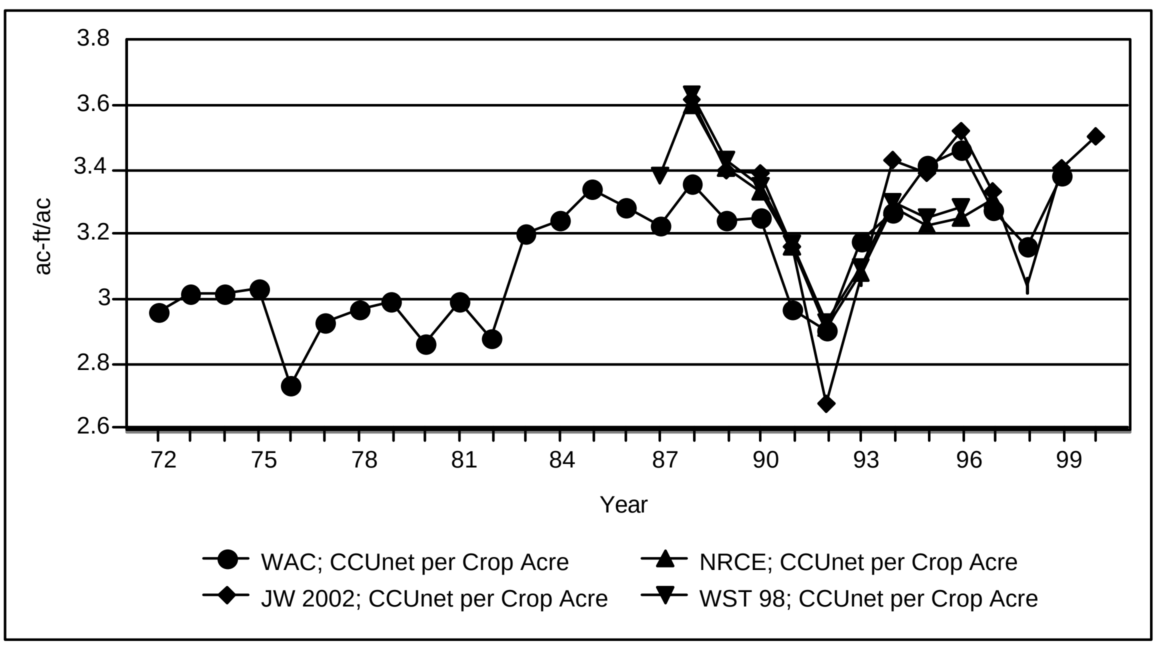

Figure 4. Annual net crop consumptive use per crop acre.

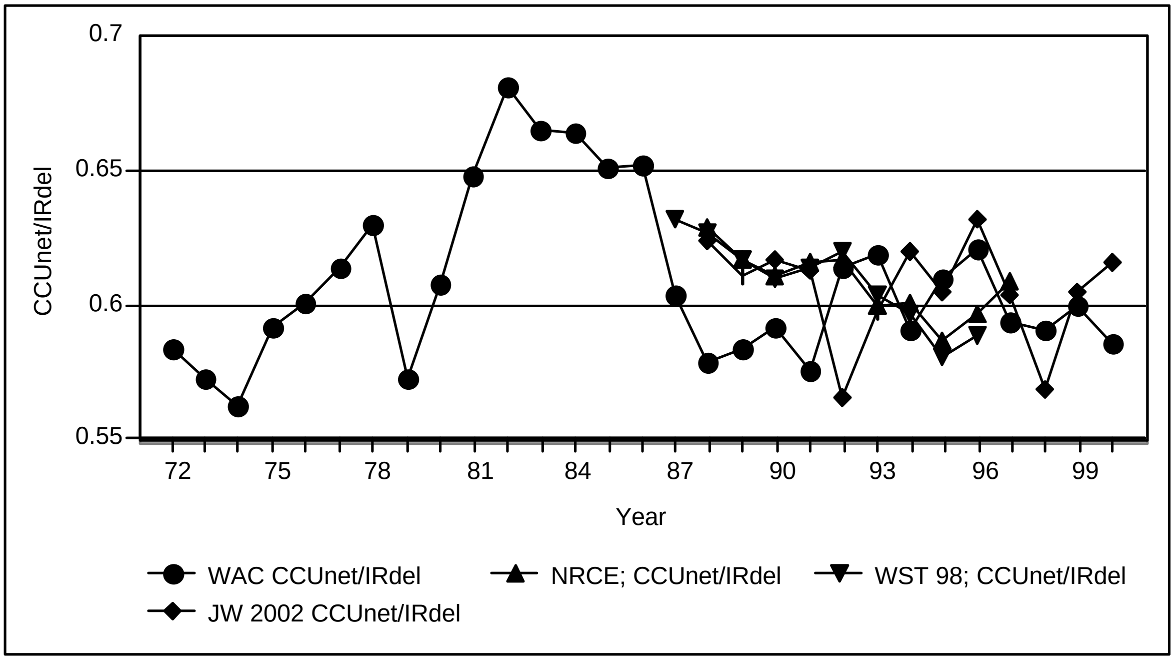

Figure 5. Comparisons of annual CCUnet/IRdel ratios, i.e., volumes of net crop consumptive use to annual delivery volume at Drop one.

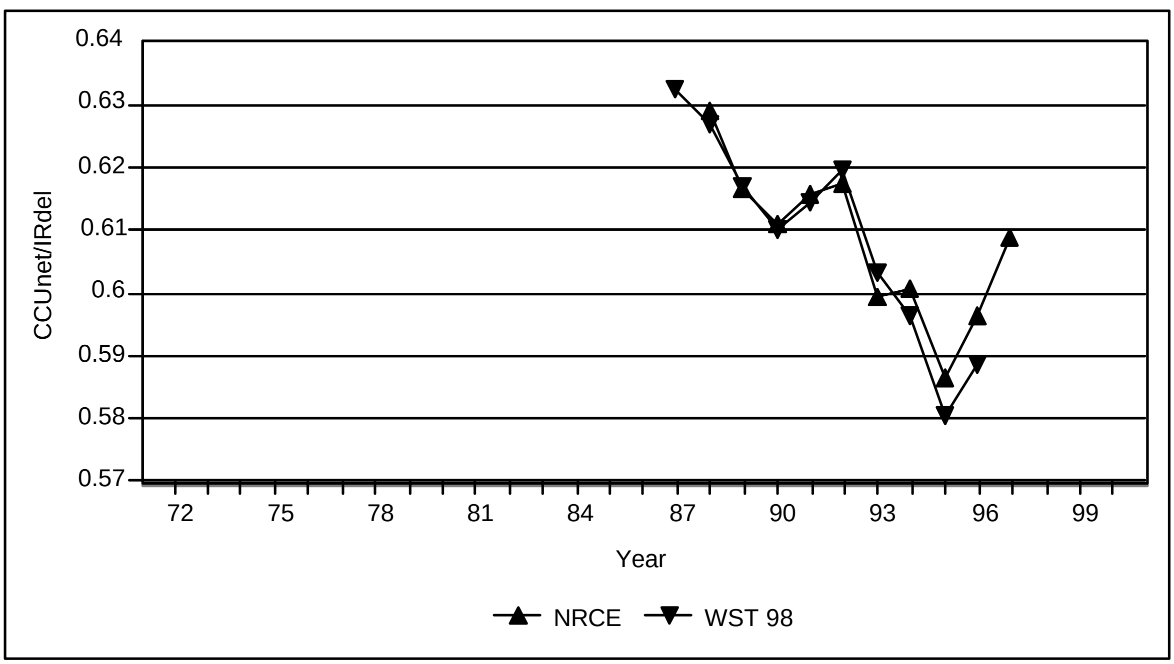

Figure 6. Comparisons of annual CCUnet/IRdel ratios for NRCE and WST assessments.

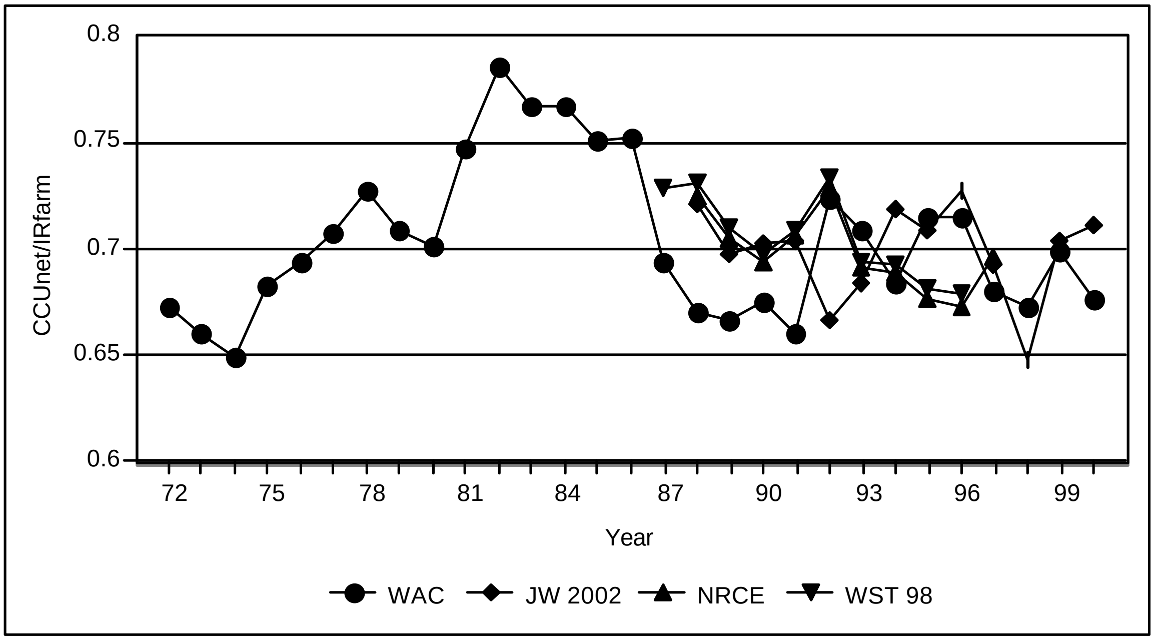

Figure 7. Comparisons of annual CCUnet/IRfarm ratios, i.e., volumes of net crop consumptive use to annual delivery to agriculture users.

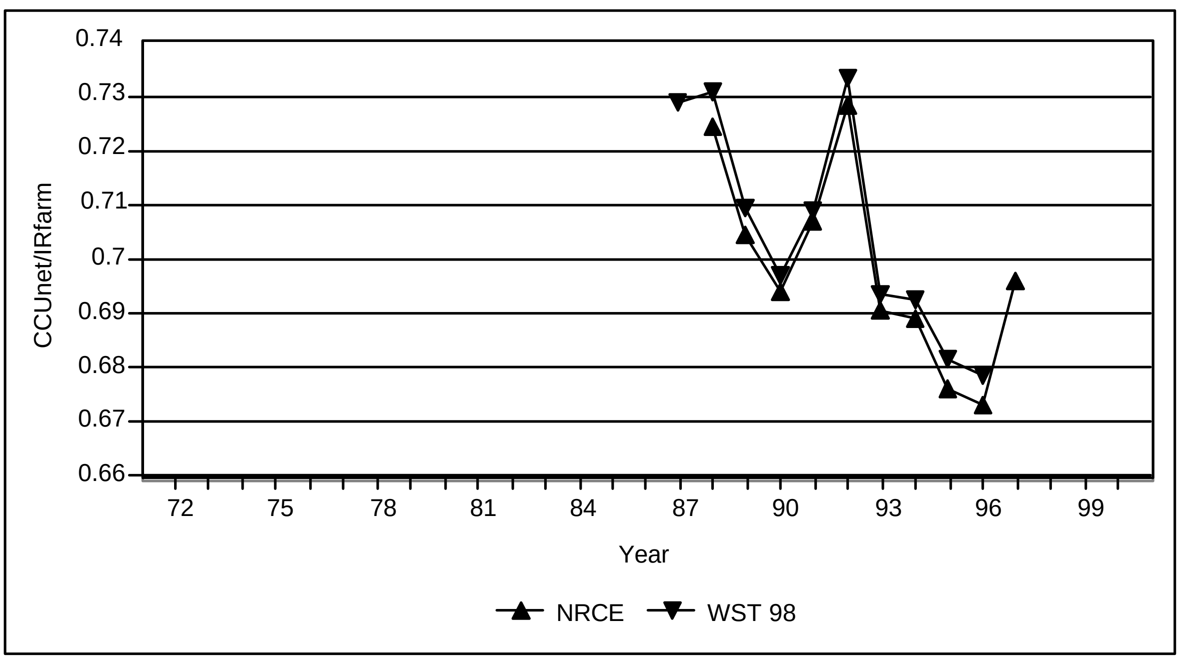

Figure 8. Comparisons of annual CCUnet/IRfarm ratios for NRCE and WST assessments.

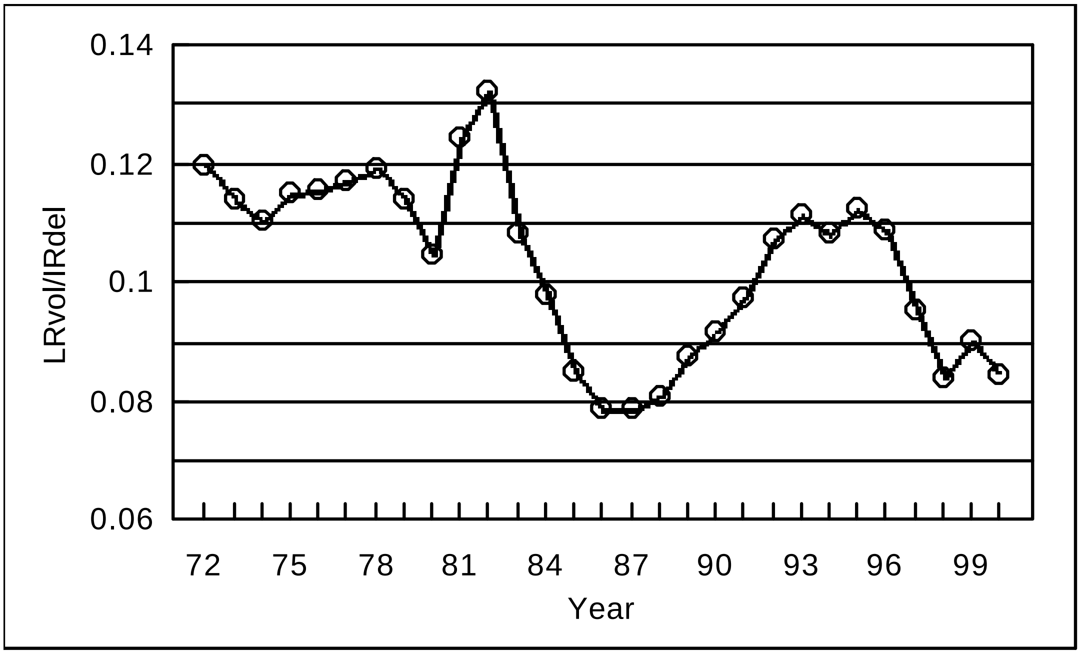

Figure 9. Leaching requirement volume (LRvol) as a ratio of irrigation agricultural delivery.

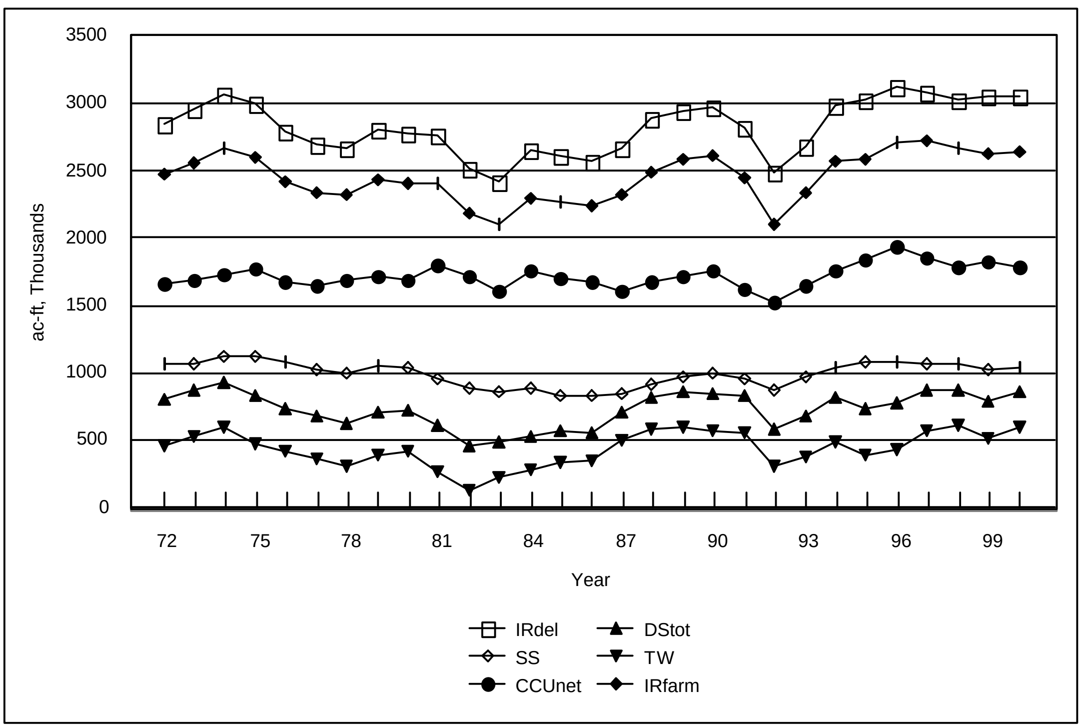

Figure 10. Comparison of annual tailwater volumes (DStot and TW) to water delivery volumes (IRdel and IRfarm), to net annual crop consumptive use volumes (CCUnet) and to net annual outflow volumes to the Salton Sea (SS)

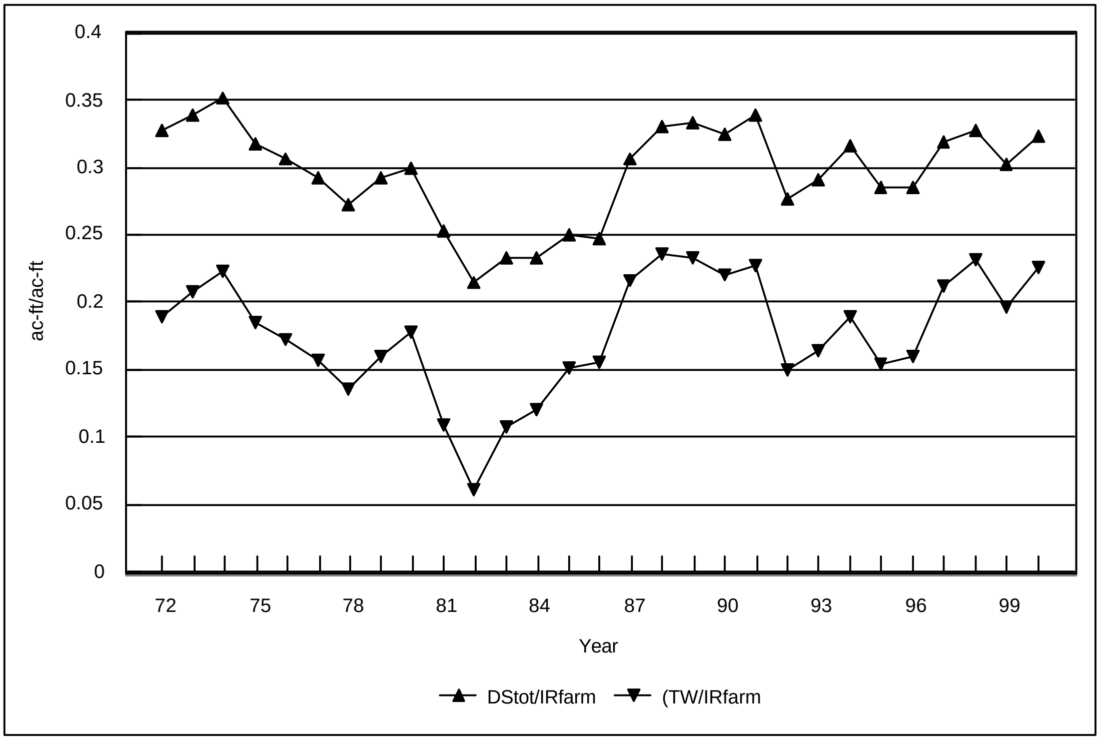

Figure 11. Annual ratios of total agricultural tailwater volume to agricultural delivery volume (DS/IRfarm) and of tailwater volume not required for leaching to agricultural delivery volume (TW/IRfarm).

IV. COMMENTS OF DR. JAMES R. GILLEY: TAILWATER RUNOFF IN THE IMPERIAL IRRIGATION DISTRICT

The amount of tailwater leaving the irrigated farms within the Imperial Irrigation District can be calculated using two different methods. The first of these is the utilization of a water balance model of the overall inflows and outflows from the District. This technique utilizes measured inflows from the All American Canal, the New and Alamo Rivers flowing across the border from Mexico, and precipitation. Other minor flows are surface runoff of storm events in the surrounding area and ground water inflow into the valley. The outflows from the District include the Alamo and New Rivers flowing to the Salton Sea plus direct flow from the District to the Sea and a minor subsurface flow to the Sea. Fortunately, the irrigation water consumption on agricultural land is by far the largest component of the district water balance.

Following the determination of water consumption of irrigation water on agricultural lands, various procedures have been used to calculate the water leaving the irrigated fields within the District. This volume of water, typically called the "irrigation water contribution to drainage" is essentially that volume of water leaving the irrigated fields as either drainage through the tile lines or surface runoff (tailwater). Techniques are then used to separate this volume into the two categories: tile water and tailwater.

The second method of determining the volume of tailwater is direct measurement of tailwater from the various fields and crops within the district and then using this sample to estimate the tailwater volume from the entire district.

A comparison of the these two methods of estimating tailwater runoff volumes from the Imperial Irrigation District will be presented here along with a discussion of the techniques utilized by the previous studies of the water assessments of the District.

A. Estimates Using Water Balance Approaches

Water Inflows. The irrigation water inflows to the District from the All American Canal are summarized in **Table 3** and shown in **Figures 12 and 13.** The data provided in **Table 1** and shown in **Figures 12 & 13** indicate that all three of the recent analyses of the Imperial Irrigation District have utilized very similar inflow information (WST, 1998; NRCE, 2002; and Jensen and Walter, 2002). Each of the reports indicate a definite increase in irrigation inflows to the Imperial Irrigation District between the years of 1987 and 1997 (**Figures 12 and 13**). Note again, that the water deliveries in 1992 and 1993 were abnormally low because of a white fly infestation on alfalfa and producers reduced their water applications on alfalfa.

Water Delivered to Farms. The irrigation water delivered to farms within the Imperial Irrigation District is summarized in **Table 4** and shown in **Figures 14 and 15.** The data utilized by both the WST (1998) and NRCE (2002) are nearly identical and are slightly higher than the data used by Jensen and Walter (2002). The primary difference is that both the WST (1998) and the NRCE (2002) used a water balance method to estimate the water delivered to irrigation and Jensen and Walter (2002) used the water delivery data provided by IID. If similar water balance methods were used to modify the Jensen and Walter data, their data would be identical to that used by the other two reports. All of the reports show a definite increase in the volume of irrigation water delivered to the farms within the Imperial Irrigation District between the years of 1987 and 1997 (**Figures 14 and 15**). Note again, that the water deliveries to farms in 1992 and 1993 were abnormally low because of a white fly infestation on alfalfa and producers reduced their water applications on alfalfa.

Irrigation Water Consumption on Agricultural Land. The irrigation water consumption on agricultural land within the Imperial Irrigation District is summarized in **Table 5** and shown in **Figure 16**. The data utilized by both the WST (1998) and NRCE (2002) are nearly identical and are slightly higher than the data used by Jensen and Walter (2002). The primary difference is that both the WST (1998) and the NRCE (2002) reports used a water balance method to estimate the irrigation water consumed on agricultural land and Jensen and Walter (2002) used a crop ET Model to calculate the crop evapotranspiration. The results of each of the studies provide quite similar values of irrigation crop water consumption within IID. Note again, that the water consumption on agricultural land in 1992 was abnormally low because of a white fly infestation on alfalfa and producers reduced their water applications on alfalfa.

Irrigation Water Entering the Drainage System from Agricultural Land. The irrigation water entering the drainage system from agricultural land within the Imperial Irrigation District is summarized in **Tables 6 and 7**, and shown in Figures **17, 18 and 19**. As shown in **Table 6** and **Figure 17**, the resulting discharge of irrigation water flow from agricultural land by both the WST (1998) and NRCE (2002) are nearly identical and greater than the results obtained by Jensen and Walter (2002), except for 1992 when the Jensen and Walter report had larger values. If the water balance changes to the on-farm water deliveries that were utilized by both the WST and NRCE reports were used with the Jensen and Walter data, the resulting irrigation water entering the drains from the Jensen and Walter report would be similar to the other two studies. Again, all of the reports show a definite increase in the volume of irrigation water flowing from agricultural land entering the drainage system within the Imperial Irrigation District between the years of 1987 and 1997 (**Figures 17 and 18**.) The volume of water leaving the agricultural fields range from a low of 737,000 acre-feet (average for 1987-97) by Jensen and Walter (2002) to a high of 846,000 acre-feet (average for 1988-1997) by NRCE (2002).

The ratio of the volume of irrigation water entering the drainage system divided by the delivered agricultural irrigation water is shown in **Table 7** and **Figure 19.** Both the WST and the NRCE reports which were commissioned by the IID indicate a growing loss of irrigation water from agriculture as expressed as a percentage of water delivered to agriculture between 1987 and 1997 with this loss approaching 35 percent. Average values for the 1987-1997 time period are as follows:

Study	Average Loss/ Ag Delivery, %
WST	31.8
NRCE	32.6
JW02	29.6
WAC	31.0

Irrigation Leaching Requirement. The estimated amount of irrigation water required to maintain a favorable salt balance (leaching requirement) is summarized in **Table 8 and Figure 20,** and the ratio of leaching requirement to agricultural deliveries is given in **Table 9** and **Figure 21.** Further details regarding the calculation procedures used to determine the volume of the required leaching fractions is given in Section IV.D. Average values of the leaching requirement are as follows:

Study	Leaching requirement (acre-feet)
WST	296,000
NRCE	263,000
J&W 02	206,000
WAC (2003)	283,000
AVERAGE	**260,000**

The leaching requirement as expressed as a percentage of agricultural deliveries ranges from a low of approximately 8 percent for the Jensen and Walter (2002) report to a high of approximately 12 percent for the WST report (**Table 9 and Figure 21**).

Irrigation Tailwater Runoff. The irrigation tailwater from agricultural land within the Imperial Irrigation District is summarized in **Tables 10 and 11**, and shown in **Figures 22, and 23**. Each of the references used slightly different procedures to determine the volume of irrigation tailwater. The WST report provided two different estimates. The first estimate utilized individual runoff data from combinations of crops and fields to determine tailwater volume. The tailwater values shown in **Table 10 and Figure 22** for the WST report utilizes their estimate of the combined tailwater and tile water and then subtracts their estimates of the required leaching requirements (**Table 8**) to maintain a favorable salt balance for each field. A similar calculation was used to obtain the tailwater estimates from the NRCE report (**Table 10 and Figure 22**).

The tailwater runoff data using the NRCE report are slightly higher than that found from the WST report because the estimated leaching requirements from the NRCE report were lower than those from the WST (**Table 8**). Using these procedures, the average annual tailwater runoff from the WST report was 543,000 acre-feet and the average from the NRCE report was 583,000 acre-feet. The average annual tailwater from the Jensen and Walter report was 530,000 acre-feet. In general, except for the unique years of 1992-1993, the volume of tailwater runoff has increased over the 1987-97 time period (**Figure 22**).

The ratio of tailwater runoff to agricultural irrigation water delivered to the farms in the Imperial Irrigation District is shown in **Table 11** and **Figure 20.** Average annual ratios of the irrigation tailwater runoff divided by the agricultural delivery were:

Study	Tailwater runoff/Ag delivery, %
WST	21.3
NRCE	22.4
J&W 02	21.3
WAC (2003)	19.7

Accordingly, the volumes of non-beneficial tailwater runoff in the Imperial Irrigation District range between 492,000 and 583,000 acre-feet annually (**Table 10,** 10 year average; and **Figure 22**). This represents between 19.7 and 22.4 percent of the water delivered to agricultural users in the District (**Table 11 and Figure 23**).

Table 3. Inflow to the Imperial Irrigation District via the All American Canal, measured at EHL.

ITEM	Source	Reference	Units	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
AAC inflow at EHL	WST[1]	WST Rpt, Table A2-16	kaf	2,667	2,851	2,922	2,957	2,798	2,475	2,676	2,949	2,969	3,057		2,832
AAC inflow at EHL	NRCE[2]	NRCE Rpt, Table V-6	kaf		2,851	2,922	2,957	2,798	2,475	2,675	2,948	2,969	3,057	3,068	2,872
AAC inflow at EHL	JW02[3]	JW02 Rpt, R 108	kaf	2,672	2,856	2,927	2,961	2,803	2,480	2,680	2,948	2,974	3,058	3,072	2,857

Table 4. Irrigation water delivered to agricultural users within the Imperial Irrigation District.

ITEM	Source	Reference	Units	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Irrigation Water Delivered to Ag Users	WST[1]	WST Rpt, Table A2-22, C6	kaf	2,390	2,571	2,641	2,670	2,520	2,202	2,402	2,670	2,684	2,770		2,552
Irrigation Water Delivered to Ag Users	NRCE[2]	NRCE Rpt, Table V-12	kaf		2,568	2,639	2,668	2,522	2,203	2,402	2,668	2,682	2,768	2,803	2,592
Irrigation Water Delivered to Ag Users	JW02[3]	JW02 Rpt, R 70	kaf	2,322	2,493	2,577	2,611	2,449	2,106	2,331	2,575	2,581	2,712	2,719	2,498

[1] Reference: Water Study Team (WST). 1998. Imperial Irrigation District Water Use Assessment for the Years 1987-1996. Report prepared for Imperial Irrigation District. Sections 1-5 and related appendices.
[2] Reference: Natural Resources Consulting Engineers (NRCE). 2002 Assessment of Imperial Irrigation District's Water Use. Sections I-VIII plus related Appendices 1-7. March 2002.
[3] Reference: Jensen, M. E. and I. A. Walter. 2002. Assessment of the 1997-2001 Water Use by the Imperial Irrigation District. Special Report for the Bureau of Reclamation, Boulder City, Nevada. November 2002. 37 pp and related Appendices A-E.

Table 5. Irrigation water consumed on agricultural land within the Imperial Irrigation District.

ITEM	Source	Reference	Units	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Irrig Water Consumed on Ag Land	WST[4]	WST Rpt, Table A2-15	kaf	1,687	1,809	1,815	1,815	1,728	1,538	1,610	1,780	1,755	1,839		1,738
Irrig Water Consumed on Ag Land	NRCE[5]	NRCE Rpt, Table V-11	kaf		1,793	1,802	1,807	1,724	1,528	1,604	1,771	1,741	1,823	1,869	1,746
Irrig Water Consumed on Ag Land	JW02[6]	JW02 Rpt, R 60	kaf	1,683	1,799	1,798	1,835	1,723	1,403	1,595	1,851	1,829	1,974	1,882	1,761

Table 6. Irrigation water entering the drainage system (Tailwater plus Tile water) from irrigated agricultural land within the Imperial Irrigation District.

ITEM	Source	Reference	UNITS	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Farm Irrig Water Entering Drain	WST[1]	WST Rpt, Table A2-23	taf	703	762	826	855	792	664	792	890	929	931		814
Farm Irrig Water Entering Drain	NRCE[2]	NRCE Rpt Table V-14	taf		775	837	861	799	675	798	897	941	945	935	846
Farm Irrig Water Entering Drain	JW02[3]	Irr Del minus Consumed	taf	639	695	779	775	726	704	736	724	752	738	837	737
Farm Irrig Water Entering Drain	WAC[7]	Irr Del minus Consumed	taf	712	824	859	849	831	582	679	813	737	773	869	775

[4] Reference: Water Study Team (WST). 1998. Imperial Irrigation District Water Use Assessment for the Years 1987-1996. Report prepared for Imperial Irrigation District. Sections 1-5 and related appendices.

[5] Reference: Natural Resources Consulting Engineers (NRCE). 2002 Assessment of Imperial Irrigation District's Water Use. Sections I-VIII plus related Appendices 1-7. March 2002.

[6] Reference: Jensen, M. E. and I. A. Walter. 2002. Assessment of the 1997-2001 Water Use by the Imperial Irrigation District. Special Report for the Bureau of Reclamation, Boulder City, Nevada. November 2002. 37 pp and related Appendices A-E.

[7] Reference: WAC. 2003

Table 7. Irrigation water entering the drainage system divided by the water delivered to agriculture within the Imperial Irrigation District.

ITEM	Source	UNITS	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Farm Irrig Water Entering Drain/Ag Del	WST[8]	%	29.4	29.6	31.3	32.0	31.4	30.2	33.0	33.3	34.6	33.6		31.8
Farm Irrig Water Entering Drain/Ag Del	NRCE[9]	%		30.2	31.7	32.3	31.7	30.6	33.2	33.6	35.1	34.1	33.4	32.6
Farm Irrig Water Entering Drain/Ag Del	JW02[10]	%	27.5	27.9	30.2	29.7	29.6	33.4	31.6	28.1	29.1	27.2	30.8	29.6
Farm Irrig Water Entering Drain/Ag Del	WAC[11]	%	30.7	33.0	33.3	32.5	33.9	27.6	29.1	31.6	28.6	28.5	32.0	31.0

Table 8. Leaching requirements as estimated by the various studies of the IID.

ITEM	Source	Reference	Units	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Leaching	WST[1]	WST Rpt, Table A2-24	taf	240	280	292	306	303	265	287	327	322	338		296
Leaching	NRCE[2]	NRCE Rpt, Table V-19	taf		241	257	264	269	234	247	284	275	290	269	263
Leaching	JW02[3]	JW02 Rpt, R 73	taf	209	223	194	218	203	152	186	225	218	237	205	206
Leaching	WAC[4]		taf	210	234	258	274	274	267	298	324	340	340	294	283

[8] Reference: Water Study Team (WST). 1998. Imperial Irrigation District Water Use Assessment for the Years 1987-1996. Report prepared for Imperial Irrigation District. Sections 1-5 and related appendices.
[9] Reference: Natural Resources Consulting Engineers (NRCE). 2002 Assessment of Imperial Irrigation District's Water Use. Sections I-VIII plus related Appendices 1-7. March 2002.
[10] Reference: Jensen, M. E. and I. A. Walter. 2002. Assessment of the 1997-2001 Water Use by the Imperial Irrigation District. Special Report for the Bureau of Reclamation, Boulder City, Nevada. November 2002. 37 pp and related Appendices A-E.
[11] Reference: WAC. 2003

Table 9. The ratio of leaching requirement to agricultural delivery as estimated by the various studies of the IID.

ITEM	Source	Units	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Leaching/Ag Del	WST[12]	%	10.0	10.9	11.1	11.5	12.0	12.0	11.9	12.2	12.0	12.2		11.6
Leaching/Ag Del	NRCE[13]	%		9.4	9.7	9.9	10.7	10.6	10.3	10.6	10.3	10.5	9.6	10.2
Leaching/Ag Del	JW02[14]	%	9.0	8.9	7.5	8.4	8.3	7.2	8.0	8.7	8.4	8.7	7.5	8.3
Leaching/Ag Del	WAC[15]	%	9.0	9.4	10.0	10.5	11.2	12.7	12.8	12.6	13.2	12.5	10.8	11.3

Table 10. Irrigation tailwater from irrigated agricultural land within the Imperial Irrigation District.

ITEM	Source	Reference	Units	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Average
Tailwater Runoff - Closure	WST[1]	WST Rpt, Table A2-24	taf	507	550	569	574	538	466	512	574	565	572		543
Tailwater Runoff - Closure	NRCE[2]	NRCE Rpt, Table V-19	taf		534	580	598	530	441	551	613	667	655	665	583
Tailwater Runoff - Closure	JW02[3]	JW02 Rpt, R 83	taf	430	472	585	557	523	552	550	499	534	501	632	530
Tailwater Runoff - Closure	WAC[4]		taf	502	590	601	575	557	315	381	489	397	433	575	492

Table 11. Irrigation tailwater divided by the water delivered to agriculture within the Imperial Irrigation District.

ITEM	Source	Units	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Avg
Ag Tailwater Runoff/Ag Del	WST[1]	%	21.2	21.4	21.5	21.5	21.3	21.2	21.3	21.5	21.1	20.6		21.3
Ag Tailwater Runoff/Ag Del	NRCE[2]	%		20.8	22.0	22.4	21.0	20.0	22.9	23.0	24.9	23.7	23.7	22.4
Ag Tailwater Runoff/Ag Del	JW02[3]	%	18.5	18.9	22.7	21.3	21.4	26.2	23.6	19.4	20.7	18.5	23.2	21.3
Ag Tailwater Runoff/Ag Del	WAC[4]	%	21.6	23.7	23.3	22.0	22.7	15.0	16.3	19.0	15.4	16.0	21.2	19.7

[12] Reference: Water Study Team (WST). 1998. Imperial Irrigation District Water Use Assessment for the Years 1987-1996. Report prepared for Imperial Irrigation District. Sections 1-5 and related appendices.
[13] Reference: Natural Resources Consulting Engineers (NRCE). 2002 Assessment of Imperial Irrigation District's Water Use. Sections I-VIII plus related Appendices 1-7. March 2002.
[14] Reference: Jensen, M. E. and I. A. Walter. 2002. Assessment of the 1997-2001 Water Use by the Imperial Irrigation District. Special Report for the Bureau of Reclamation, Boulder City, Nevada. November 2002. 37 pp and related Appendices A-E.
[15] Reference: WAC. 2003

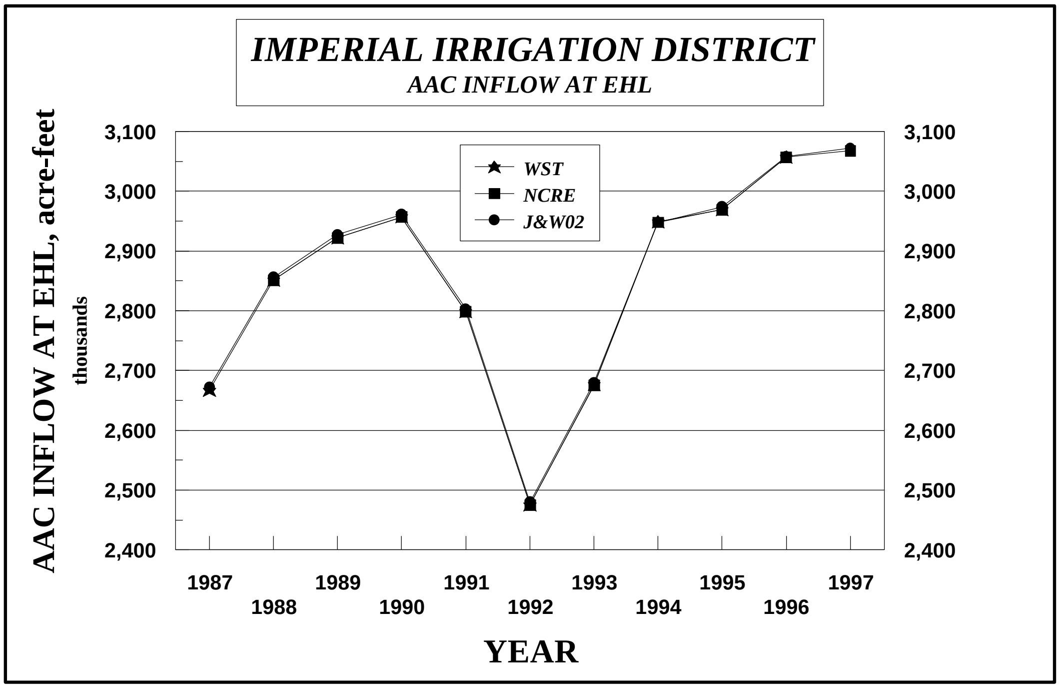

Figure 12. Inflow to the Imperial Irrigation District via the All American Canal, measured at EHL.

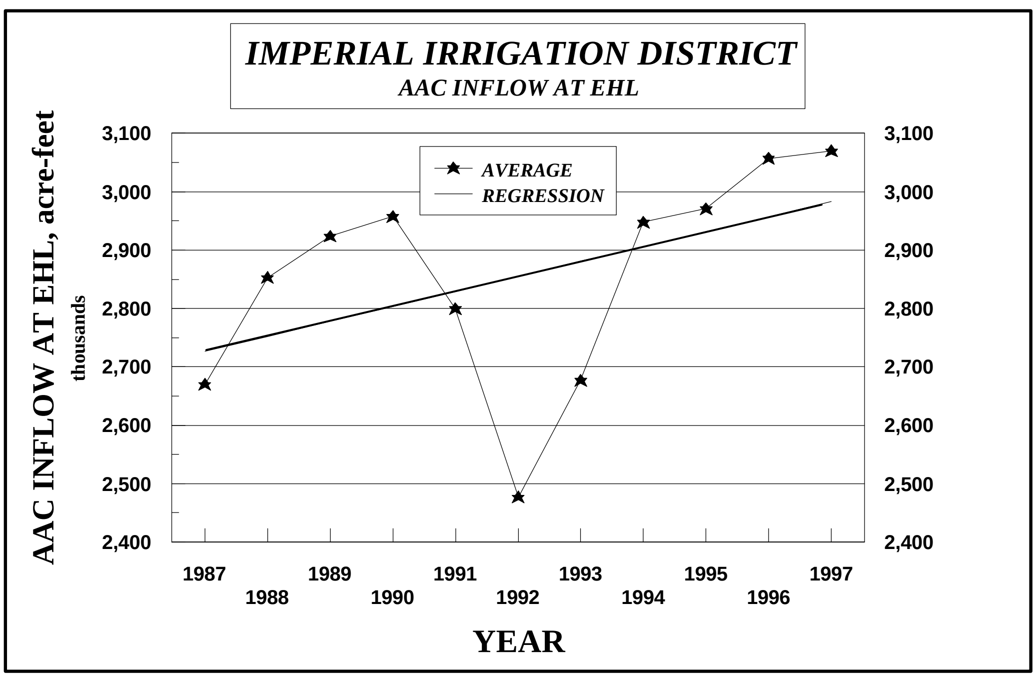

Figure 13. Inflow to the Imperial Irrigation District via the All American Canal, measured at EHL. Average from the three reports (WST, 1998; NRCE, 2002; and Jensen and Walter, 2002).

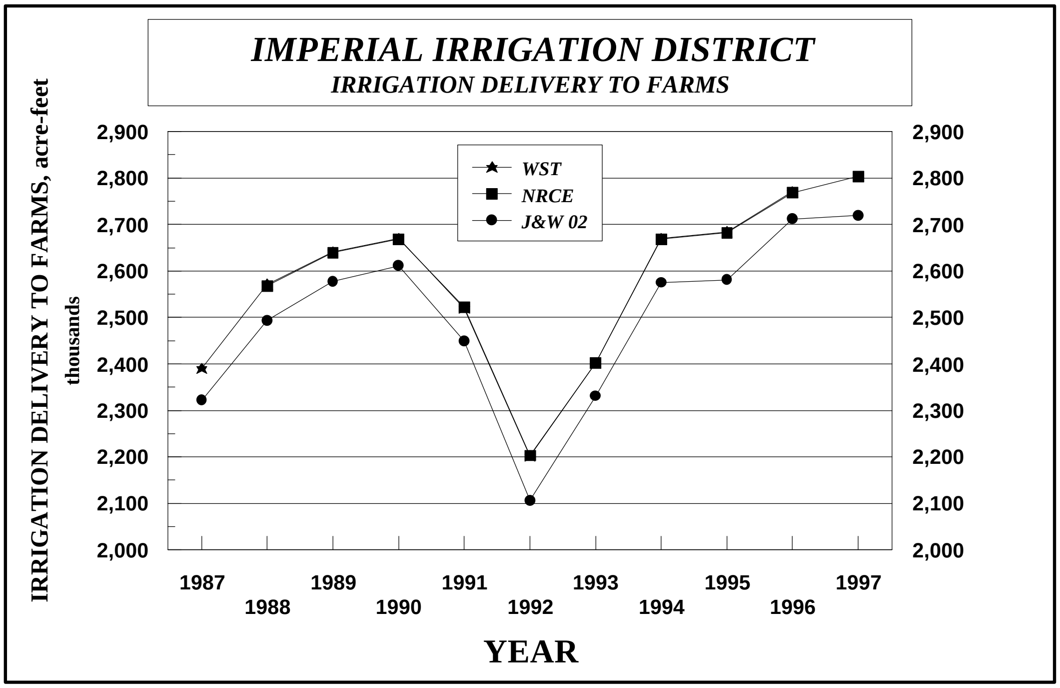

Figure 14. Irrigation water delivered to Agricultural Users within the Imperial Irrigation District.

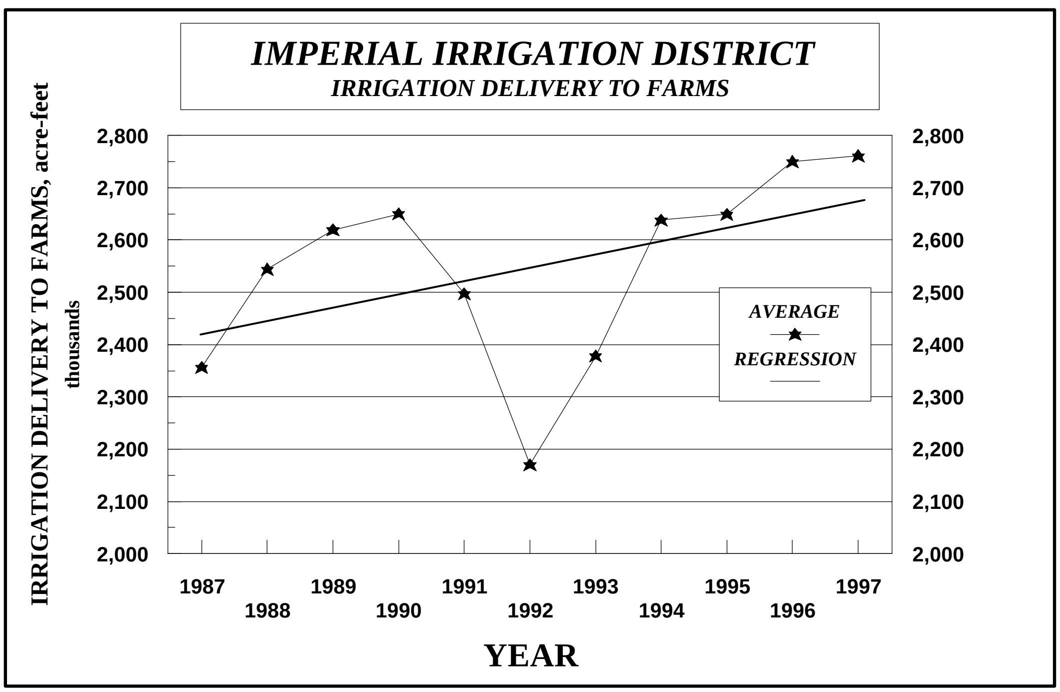

Figure 15. Irrigation water delivered to Agricultural Users within the Imperial Irrigation District. Average from the three reports (WST, 1998; NRCE, 2002; and Jensen and Walter, 2002).

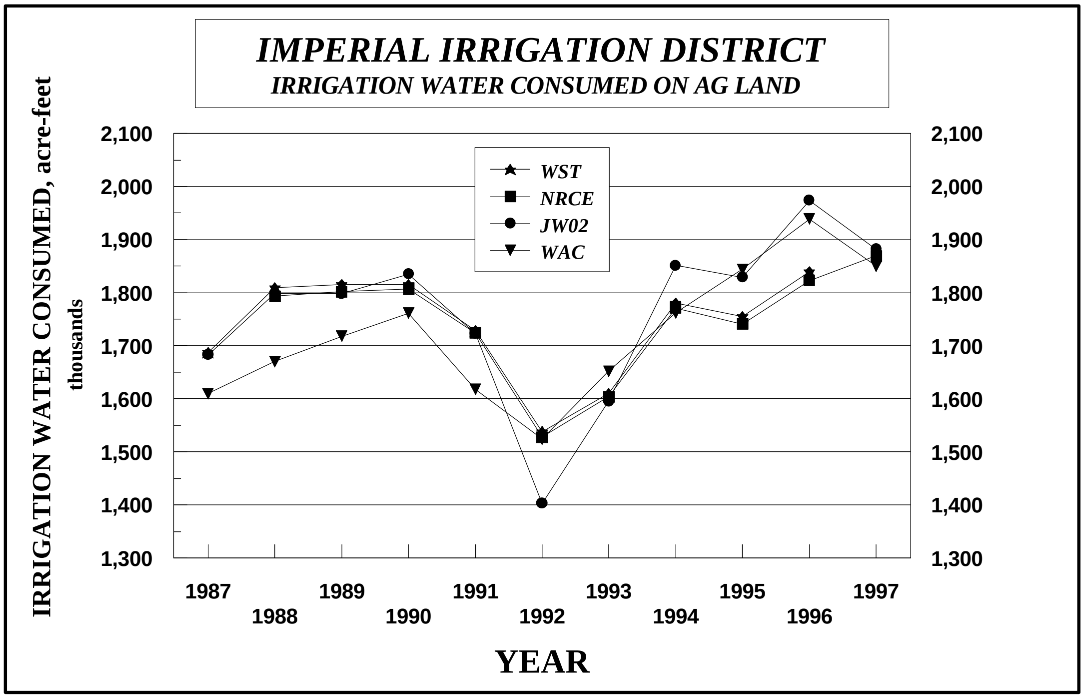

Figure 16. Irrigation water consumed on agricultural land within the Imperial Irrigation District.

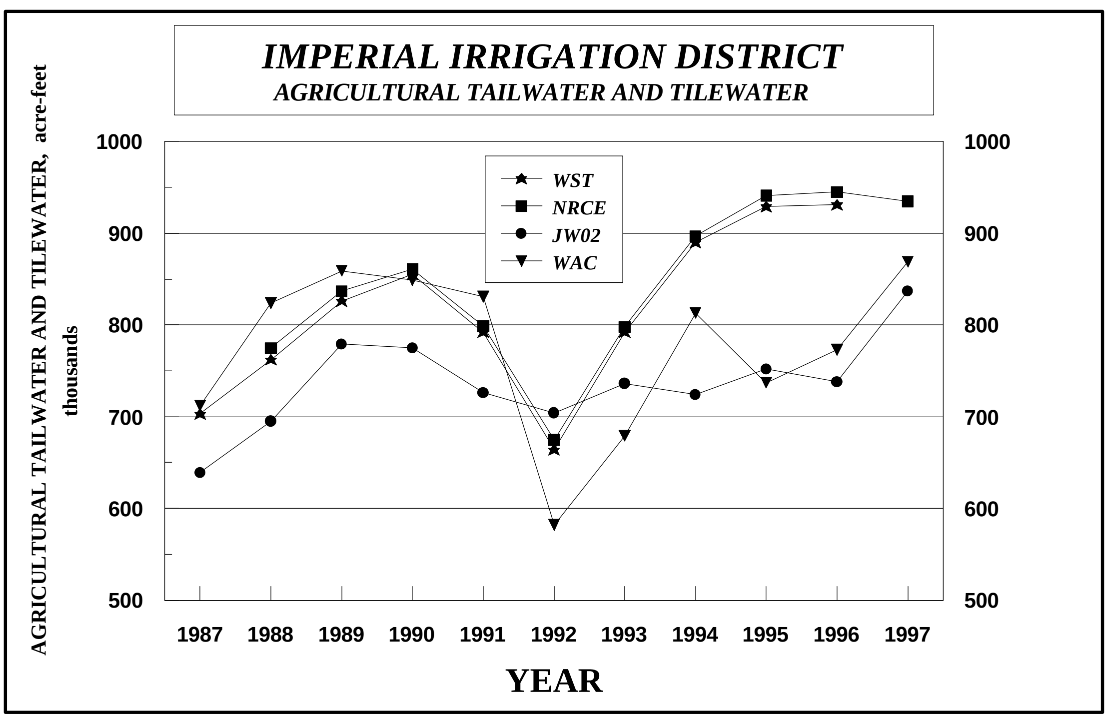

Figure 17. Irrigation tailwater and tile water from agricultural land within the Imperial Irrigation District.

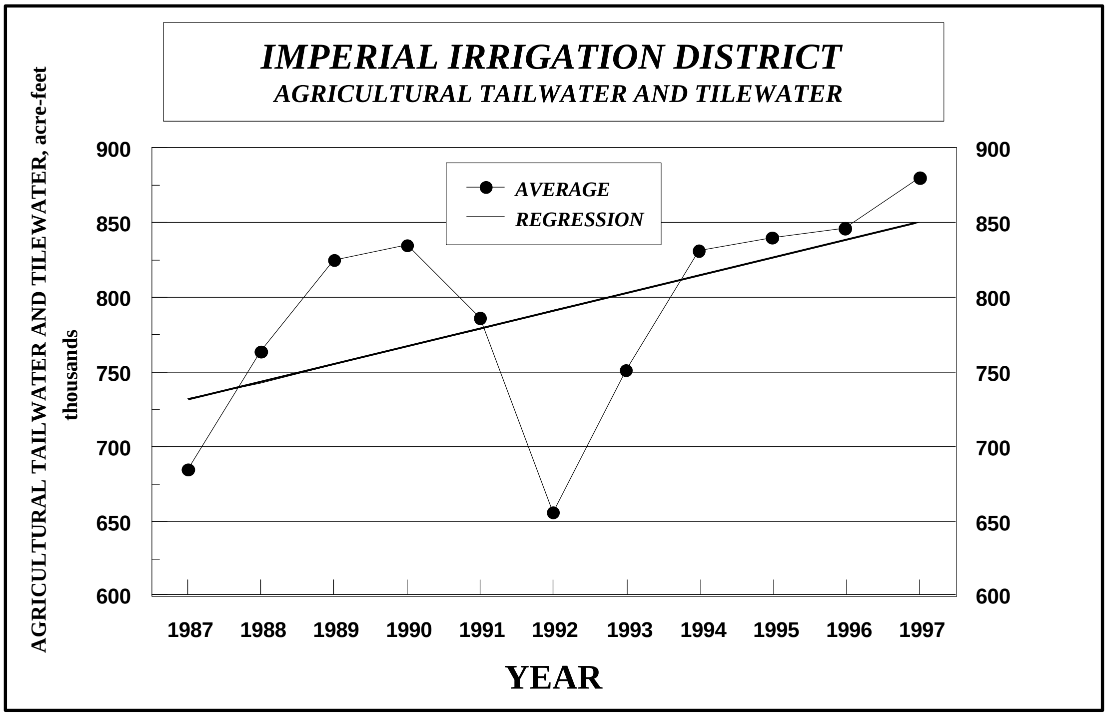

Figure 18. Average irrigation tailwater and tile water from agricultural land within the Imperial Irrigation District. Average from the three reports (WST, 1998; NRCE, 2002; and Jensen and Walter, 2002).

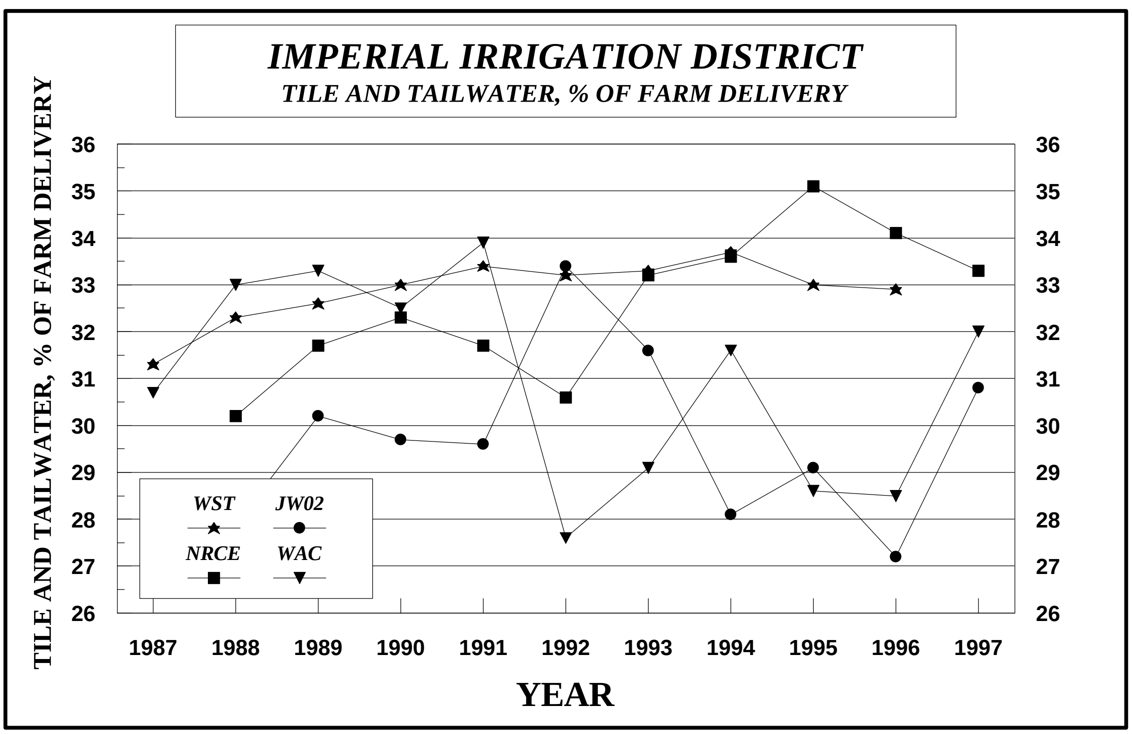

Figure 19. Irrigation tailwater and tile water as a percentage of irrigation water delivered to agricultural land within the Imperial Irrigation District.

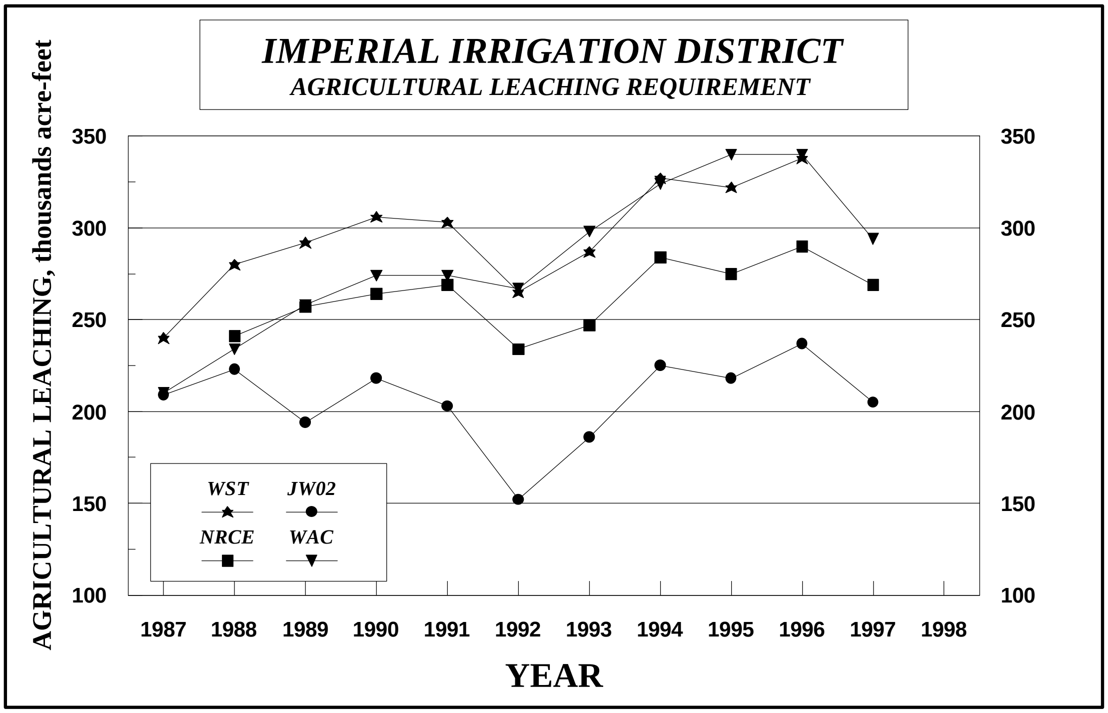

Figure 20. Irrigation leaching requirement from agricultural land within the Imperial Irrigation District.

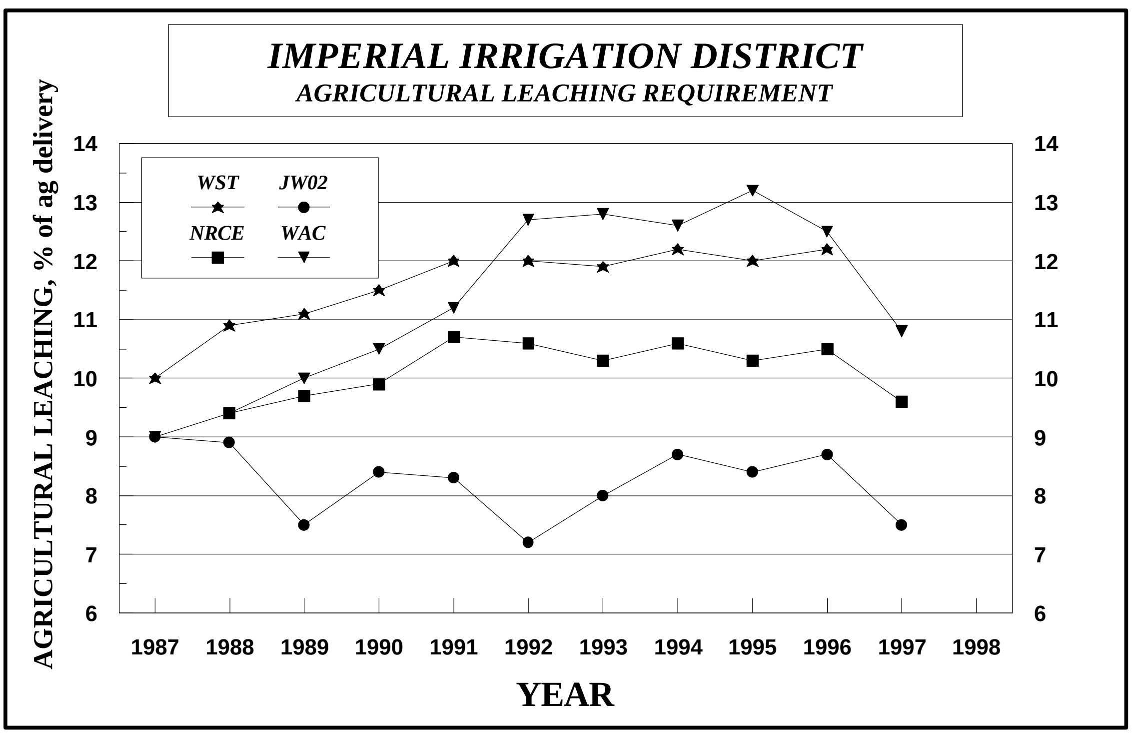

Figure 21. Irrigation leaching requirement as a percentage of irrigation water delivered to agricultural land within the Imperial Irrigation District.

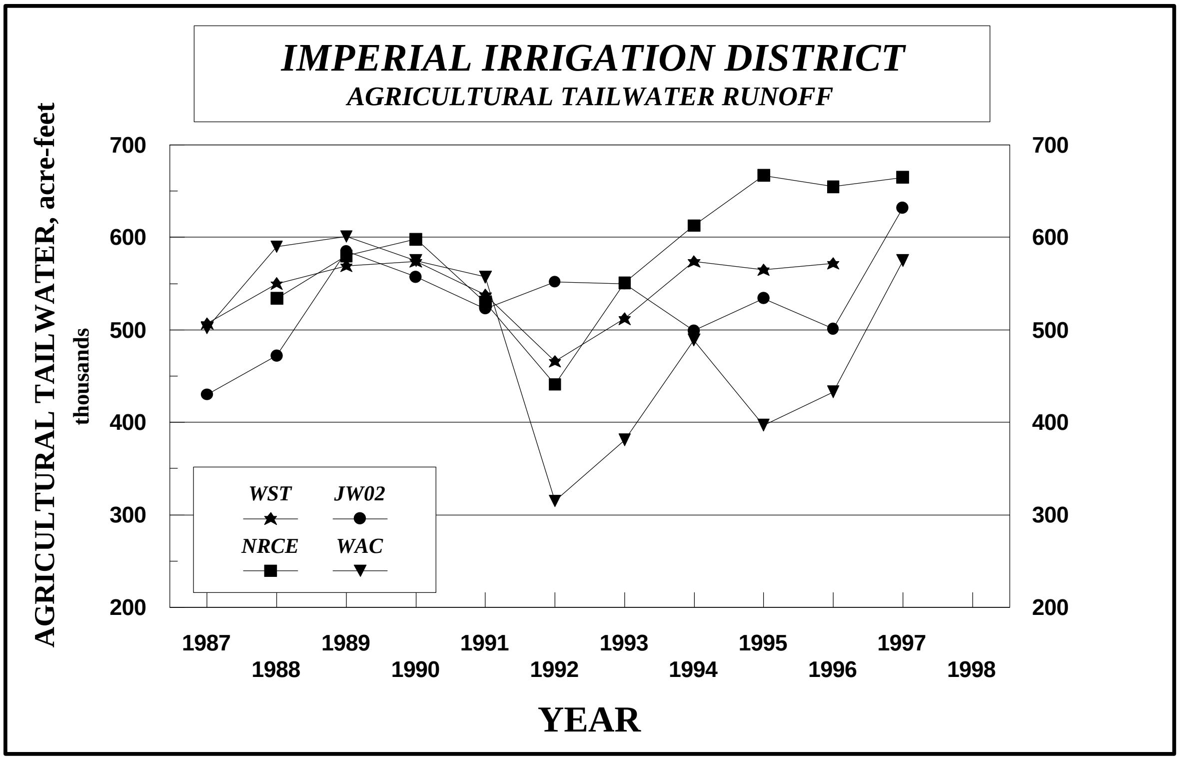

Figure 22. Irrigation tailwater from agricultural land within the Imperial Irrigation District.

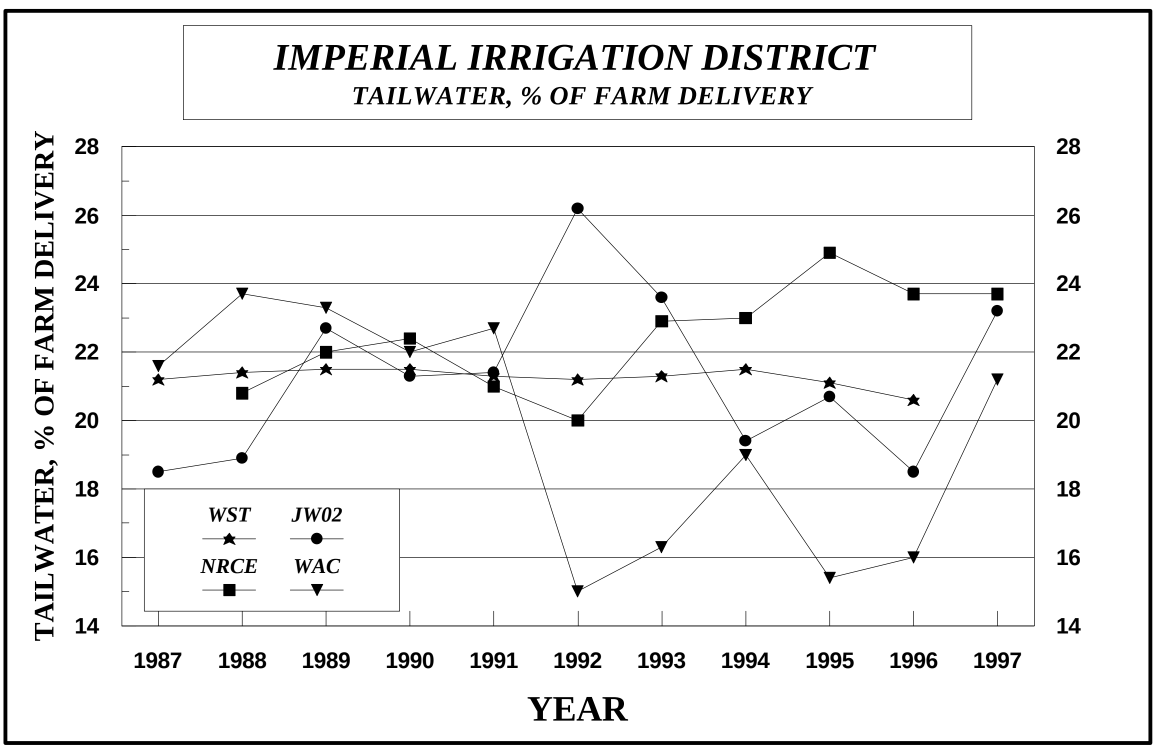

Figure 23. Irrigation tailwater as a percentage of farm delivery to agricultural land within the Imperial Irrigation District.

B. Tailwater Runoff From Individual Irrigation Events And Fields

The amount and distribution of runoff from surface irrigation systems (tailwater) has been measured in several locations over many years, including the Imperial Irrigation District (Oster, et al., 1986; Boyle Engineering Corporation, 1990 and O'Halloran, 1990).

Oster et al. (1986) summarized the results of an intensive irrigation evaluation study conducted in the Imperial Irrigation District for the years between 1977-1981. Surface irrigation tailwater runoff and its variation by crop for those fields evaluated by Oster (1986) are summarized in **Figure 24.** Average tailwater runoff varies from a low of 16.5 percent for alfalfa to a high of 38 percent for melons. The variation of tailwater runoff as a percentage is shown in Figure 22. While most of the runoff ranges between 5 and 20 percent, there are runoff events where the tailwater runoff exceeds 40 percent (**Figure 25**).

The probability distribution of the tailwater runoff from each of the fields evaluated by Oster (1986) is shown in **Figure 26.** The data presented in **Figure 26** clearly demonstrates the field to field variation in tailwater runoff and the different management levels incorporated into the individual irrigation events. Mean values of tailwater runoff (50% probability) vary between 11 percent (Field 8) and 26 percent on field 1 (**Figure 26**).

Returning to crop data, the probability distribution of tailwater runoff from the fields producing alfalfa is shown in **Figure 27**. The 50% probability tailwater runoff ranges from approximately 11% for field number eight to 24% for field number three. The variation in tailwater runoff between those fields producing alfalfa indicates that the management of individual irrigation events is critical in controlling tailwater runoff from surface irrigated fields.

Tailwater runoff values, measured by the Imperial Irrigation District staff, were obtained from an inter-office memo from O'Halloran (1990) and are summarized in **Table 12**. Average tailwater runoff values ranged from a low of 13.2% for alfalfa to a high of 28.5% for onions.

The Imperial Irrigation District funded and conducted a Tailwater Recovery Demonstration Program between 1985 and 1990 (Boyle Engineering Corporation, 1990). Five pump back tailwater recovery systems were designed and installed on grower/cooperator fields and intensively monitored to determine potential impacts on soil and water resources resulting from recycled tailwater in the District. The program cooperators indicated that the operation of the pump back systems was a successful alternative to reduce surface tailwater discharges to the drain and to facilitate water conservation.

The results of these demonstrations (Boyle Engineering Corporation, 1990) are given in **Table 13** and shown in **Figure 28**. The weighted average of tailwater runoff (expressed as a percentage of the water delivered to the fields) for the five demonstration systems was 22.9 percent (**Table 11**). The tailwater runoff (expressed as a percentage of the water delivered to the field) varied from a low of 6.7 percent for cotton to a high of 37.7 percent for onions (**Figure 28**).

The analysis presented here clearly indicates a wide variation in tailwater runoff volume leaving the irrigated fields within the Imperial Irrigation District. Further, large differences in tailwater runoff volume exist throughout the year for any given field. Usually, the largest runoff values are associated with the initial irrigation following planting/or land preparation.

This initial irrigation usually results in larger infiltration depths resulting from slower rates of water advance across the field and higher infiltration rates. In most cases, the irrigation depths applied in the first irrigation are much larger than the depth needed for crop growth during this time period. Furthermore, the initial irrigation events of the year often result in surface runoff. While, deep percolation may provide some beneficial reclamation leaching, the tailwater runoff is clearly non-beneficial and unjustified.

Table 12. Tailwater runoff by crop in the Imperial Irrigation District. Data from O'Halloran (1990).

CROP	AVERAGE DELIVERY acft	AVERAGE TAILWATER acft	AVERAGE TAILWATER %	NUMBER OF RECORDS
Onions	24.6	7.0	28.5	92
Sugar Beets	36.1	7.6	21.1	669
Row Alfalfa	41.6	8.7	20.9	829
Cotton	34.1	6.3	18.5	615
Melons	24.8	4.2	16.9	48
Bermuda Grass	33.0	5.2	15.8	280
Sudan Grass	40.8	6.1	15.0	154
Wheat	36.1	5.2	14.4	470
Alfalfa	36.3	4.8	13.2	4259
Flat Flood	77.6	4.9	6.3	73
Flat Crops	36.6	5.3	14.5	5163
Row Crops	34.1	7.4	21.7	2205

Table 13. Tailwater recovery from the Tailwater Recovery Demonstration Program in the Imperial Irrigation District, 1985-1990. Data taken from Appendix A through E of Boyle Engineering Corporation (1990).

PUMPBACK SYSTEM NUMBER	TAILWATER RUNOFF AVERAGE %	TAILWATER RUNOFF STD DEV %	TAILWATER RUNOFF COEFFICIENT OF VARIATION
1	**25.90**	**22.51**	**0.87**
2	**22.09**	**15.20**	**0.69**
3	**14.40**	**8.77**	**0.61**
4	**16.18**	**16.02**	**0.99**
5	**34.86**	**20.07**	**0.58**
ALL	**22.91**	**19.54**	**0.85**

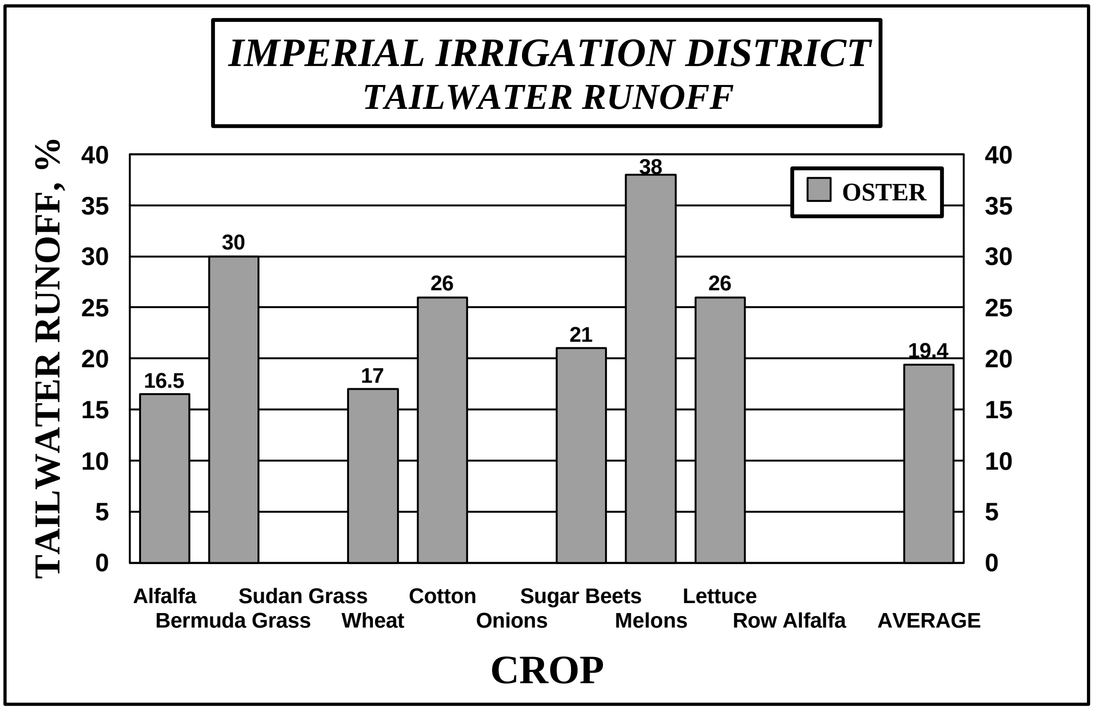

Figure 24. Tailwater runoff from Imperial Irrigation District. Data from Oster et al (1986).

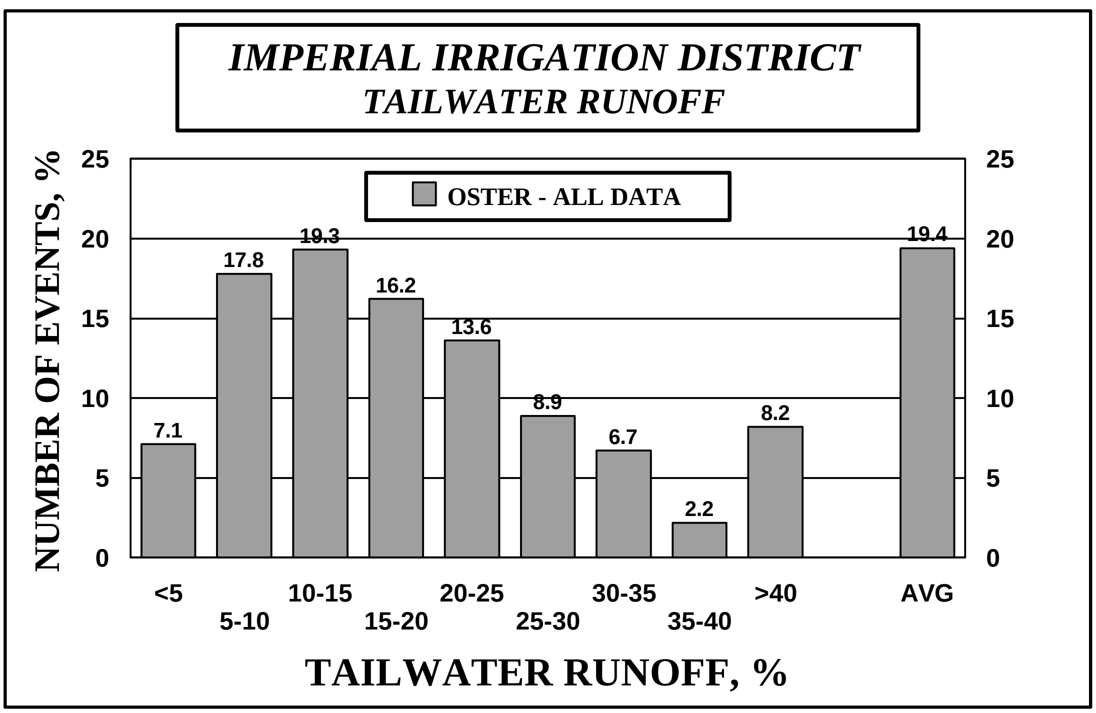

Figure 25. Surface irrigation tailwater runoff from fields within the Imperial Irrigation District over a five-year time period (1977-1981). Adapted from Oster et al. (1986).

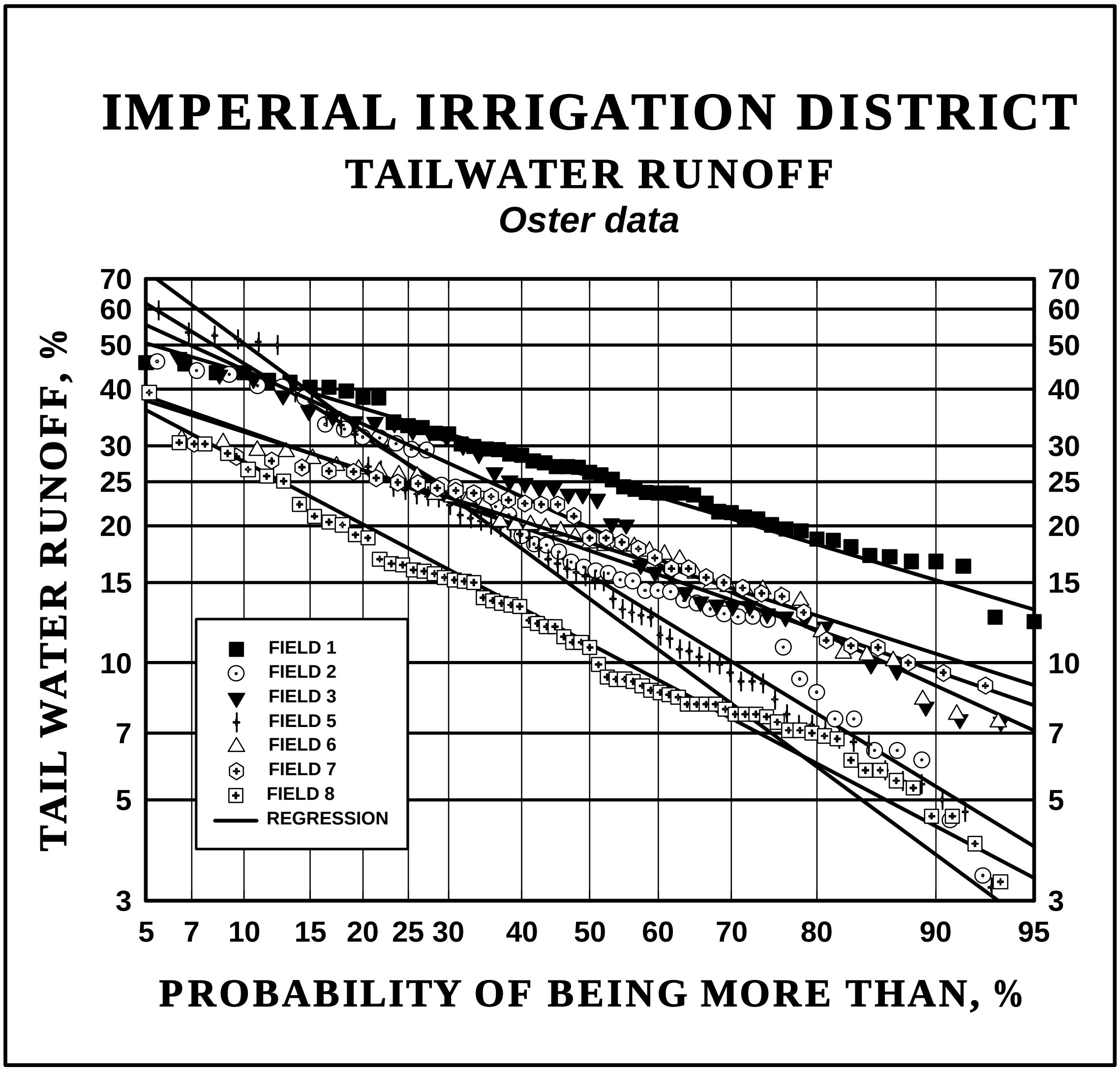

Figure 26. Surface irrigation tailwater runoff from fields within the Imperial Irrigation District over a five-year time period (1977-1981). Adapted from Oster et al. (1986).

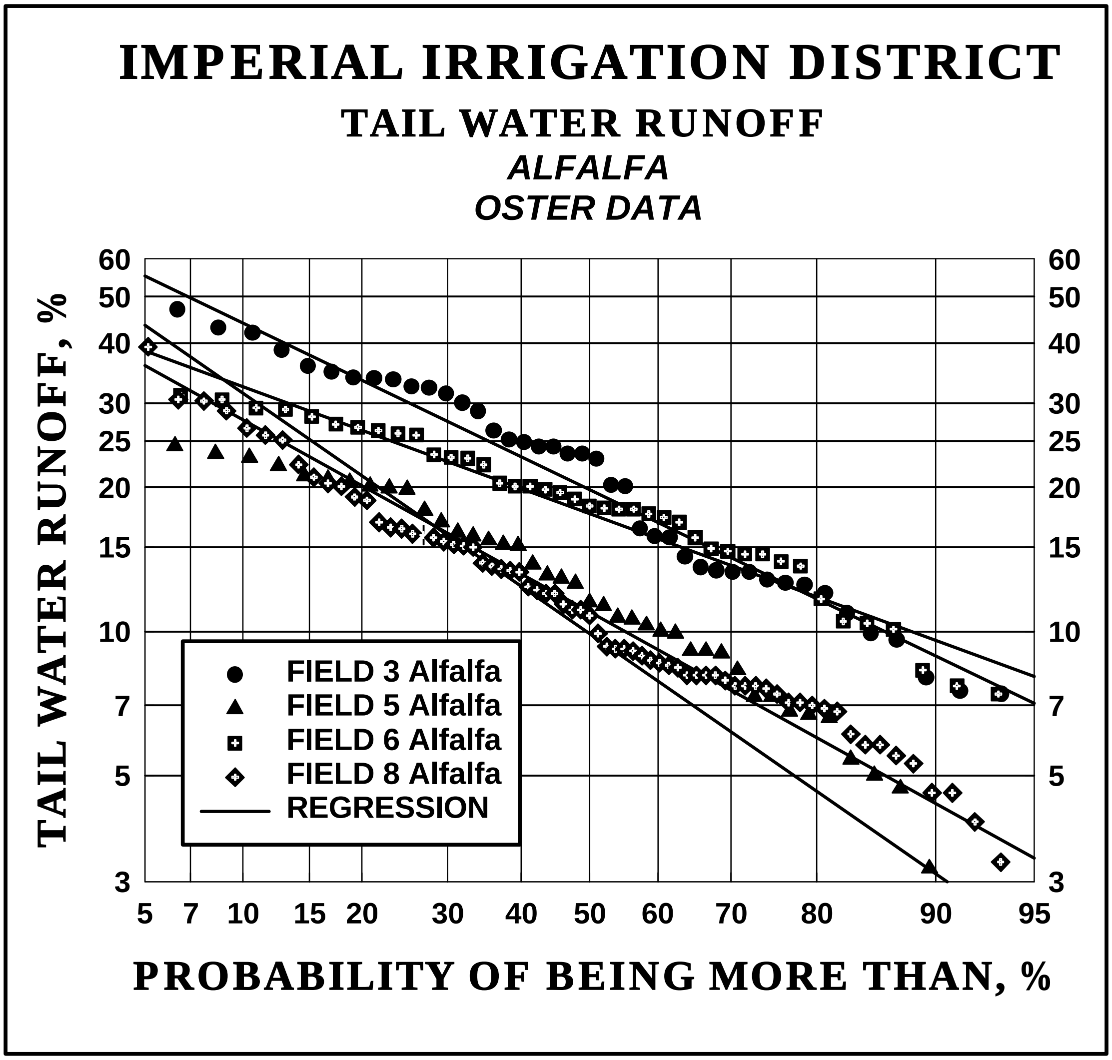

Figure 27. Surface irrigation tailwater runoff from four alfalfa fields within the Imperial Irrigation District over a five-year time period (1977-1981). Adapted from Oster et al (1986).

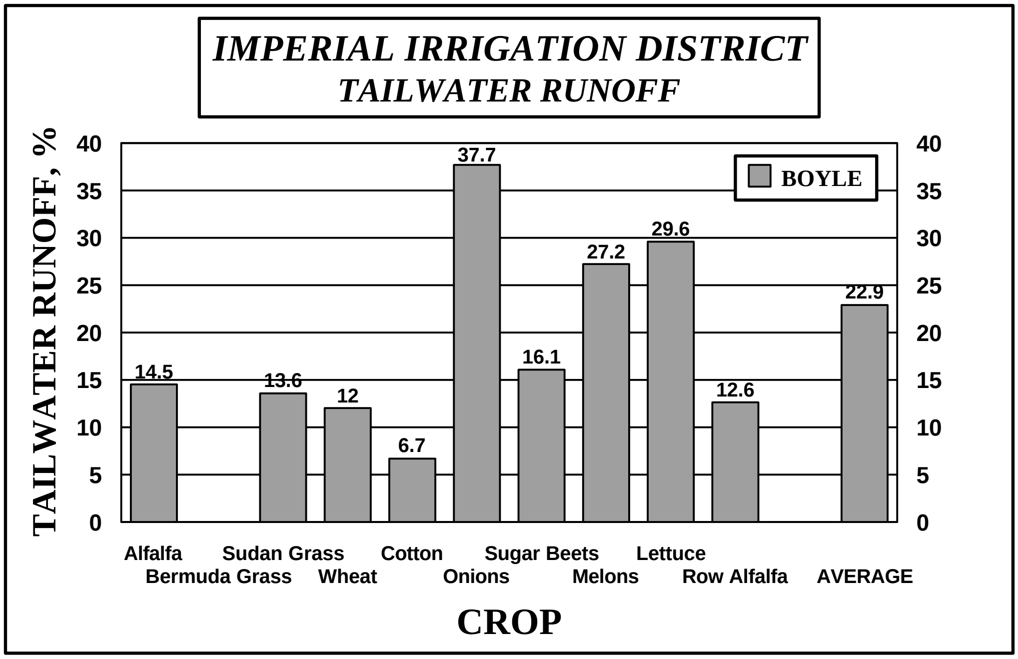

Figure 28. Tailwater runoff by crop in Imperial Irrigation District. Data from Boyle Engineering Corporation (1990).

C. Discussion of Tailwater Management on Irrigation Events Evaluated By NRCE

Reduction of Tailwater on the Cracking Clay Soils within IID. For cracking-clay soils the volume or depth of infiltration does not depend on the ponding time after the cracks swell shut. Van der Tak and Grismer (1987) as well as Waller and Wallender (1991) observed linear advance on Imperial clay soils and the latter authors reported linear advance on Tulare soils in the San Joaquin Valley. Linear advance of flow and steady surface flow along the border indicates that the soil infiltration rate is zero. Measurements of infiltration from changes in soil moisture were independent of measured intake opportunity time and thus demonstrated that there was no correlation between intake opportunity time and infiltration.

For sloped fields on Imperial clay soils in which inflow rate is steady and the infiltration quickly approaches near zero after ponding, the flow rate leaving the distal end increases sharply to approximately the flow rate applied at the upstream end. The tailwater runoff remains steady until water is stopped at the upstream end. Any tailwater runoff following the crack filling at the field end is wasted.

In summary, a single measurement of advance time to a fractional distance along the border (Grismer and Tod, 1994) combined with knowledge of inflow rate and flow depth at the upstream end can be used to calculate the average infiltration depth as well as cutoff time to avoid runoff on cracking clay soils. This technique, when applied to the cracking clay soils within the Imperial Irrigation District, could significantly reduce the tailwater from each irrigation event.

The procedures of Grismer and Tod (1994) were utilized within the Imperial Irrigation District over a three year period (Bali et al., 1999) and have been published in peer-reviewed journals by Grismer and Bali (2001) for sudan grass and by Bali et al. (2001) for alfalfa. The details of the cut-off time method of reducing tailwater runoff are provided by Bali et al. (1999). When applying the method to cracking clay soils, the primary objective is to irrigate using sufficient water to fill the soil cracks with little or no runoff. The authors (Bali et al., 1999) report that "Significant amount of runoff was saved as a result of the implementation of this method."

In a three-year study on moderately saline field soils of the Valley (Bali et al., 2001), tailwater runoff was reduced to less than two percent, thereby reducing the annual water application by approximately 28% with no loss in alfalfa hay yield or quality in comparison to countywide averages. Soil salinity accumulated (from 6 to 14 dS/m) at the 0-1.5 m depth interval of the soil profile, particularly in the lower 15% of the border checks by the end of the study. However, disking, a single leaching irrigation, and sweet corn production after termination of alfalfa were adequate to reclaim the soil. Reduced water application occurred through reduction of tailwater runoff to less than two percent throughout the study. It was suggested that the reduced-runoff method may be successfully applied in the Imperial Irrigation District as a water conservation procedure. Tod and Grismer (1999) determined that the production costs with use of the method are slightly less than the IID average, suggesting that this method is also economically feasible. Similar results were obtained for sudan grass grown in the Imperial Irrigation District (Grismer and Bali, 2001). For this crop, the reduced-runoff method reduced the seasonal irrigation water application by approximately 1.3 feet through a reduction of tailwater runoff without incurring additional production costs.

Irrigation Events Monitored by the NRCE. A summary of ten individual irrigation events within IID which were monitored by the NRCE (2002) are provided in **Table 14**. Tailwater runoff from these individual irrigations range between zero and 28 percent. The two events with zero tailwater were 1) field number 4 (fine sand soil) which was under irrigated, and 2) field number 10 when tailwater was pumped to the head ditch. The remaining 8 irrigation events had tailwater runoff of between 6 and 28 percent, and for the field having 6 percent (field 5), resulted from turning the water off before reaching the end of the field. Average tailwater from the cracking clay soils was over 17%

Nine of the evaluations were on fine textured soils of the cracking-clay type. Comments provided by NRCE personnel conducting the tests were: "near constant rate of advance. Quite Uniform." These observations are an indication of the water movement over cracking-clay soils. The observations on field number 5 were a classic case of turning off the water before it reaches the end of the field. Similar results (reduced or eliminated tailwater) could have been obtained on each of the fields having cracking-clay soils. These soils are obvious candidates for the procedures described by Bali et al. (1999) for alfalfa grown in the Imperial Irrigation District. Throughout a three year production for alfalfa a net reduction in annual water application of approximately 28 percent was achieved with no apparent loss in alfalfa hay yield or quality (Bali et al., 2001). Similar results were obtained for sudan grass grown in the Imperial Irrigation District (Grismer and Bali, 2001).

Table 14. Summary of field irrigation evaluations performed by NRCE. [16]

Field Number	Type of Irrigation	Soil Type	Crop	Irrigation Date	Water Applied in	Tailwater in	Tailwater % of Applied	Comments
1	Borders	Silty Clay	Alfalfa	6/22-23/00	3.8	1.1	28	Near constant rate of advance. Quite Uniform
2	Borders	Silty Clay	Alfalfa	6/23-24/00	3.8	0.5	14	Near constant rate of advance. Quite Uniform
3	Borders	Silty Clay	Alfalfa	6/25-27/00	4.3	0.6	13	Near constant rate of advance. Quite Uniform
4	Borders	Fine Sand	Alfalfa	6/29-30/00	4.3			No tailwater. Under irrigation at bottom and excess at top
5	Borders	Silty Clay	Bermuda	7/11-12/00	5.1	0.3	6	Near constant rate of advance. Quite Uniform. Water shut off at 70 % of length.
6	Borders	Silty Clay	Sudan grass	7/13-15/00	5.2	0.6	12	Near constant rate of advance. Quite Uniform
7	Borders	Silty Clay Loam	Alfalfa	7/14-16/00	6.4	1.2	20	Near constant rate of advance. Good
8	Furrow	Silty Clay	Alfalfa	7/15-16/00	3.8	0.8	20	Some furrows advanced faster. Runoff quite high.
9	Borders	Silty Clay Loam	Bermuda	7/18-19/00	3.3	0.6	20	Near constant rate of advance. Good
10	Borders	Silty Clay Loam	NONE	6/23-7/03	9.8			Tailwater was pumped to head ditch.

[16] Reference: Natural Resources Consulting Engineers (NRCE). 2002 Assessment of Imperial Irrigation District's Water Use. Sections I-VIII plus related Appendices 1-7. March 2002. Data from Appendix 7.

D. Tailwater Runoff In The Imperial Irrigation District Is A Non-Beneficial Use Of Colorado River Water

Surface tailwater runoff from irrigated fields discharged into Salton Sea through agricultural drains is a non-beneficial use of water. Results of tailwater evaluations from individual farms, fields and crops provide significant evidence that "average" tailwater volumes are approaching 23 percent (Boyle Engineering Corporation, 1990). Water balance evaluations of the entire Imperial Irrigation District by reports commissioned by IID (WST, 1998 and NRCE, 2002) provide tailwater estimates of between 21.3 and 22.4 percent of the farm deliveries.

The discharge of tailwater from farms or the district should be prohibited. There are several reasonable and economically attractive methods for effectively eliminating tailwater runoff within the Imperial Irrigation District. These range from capital-intensive design, installation and management of reservoir water reuse systems to the application of improved irrigation management of cracking-clay soils. Viable tailwater management alternatives result in water conservation costs between $30 and $60 per acre-foot of conserved tailwater (WAC, 2003). However, **it is much more difficult and expensive to capture and pumpback tailwater, once created, than to control the flow of irrigation water to minimize the amount of tailwater produced.**

There are very effective and inexpensive irrigation water management practices which can be easily incorporated onto the cracking clay soils in the Imperial Irrigation District. On the cracking clay soils of the Imperial Irrigation District the water infiltration during surface irrigation is zero or near zero shortly after ponding. Because the infiltration rate is zero or near zero, the speed of water advance along borders is constant and surface flow along the border is steady shortly after ponding. Further evidence of this infiltration behavior is that there is no correlation between ponding time and total infiltration. Accordingly, there are readily available procedures that can be used to greatly reduce the amount of tailwater from surface irrigation. This was amply demonstrated by the evaluation of these reduced-runoff procedures for alfalfa and sudan grass grown in the Imperial Valley, California (Bali et al., 1999).

The Imperial Irrigation District has not effectively implemented tailwater runoff policy, nor conservation practices similar to those already in existence in irrigation districts in both California and other states in the U.S. If the Imperial Irrigation District would aggressively enforce its own Triple Charge penalty for tailwater, there would be water savings exceeding 200,000 acre-feet per year.

V. COMMENTS OF DR. KENNETH K. TANJI AND DR. WESLEY W. WALLENDER: SALINITY OF SOIL AND WATER AND EFFECTIVENESS OF TAILWATER LEACHING

A. Comments on NRCE's Report on Assessment of Imperial Irrigation District's Water Use, dated March 2002 by Dr. Kenneth K. Tanji

1. Page I-2, para.6, lines 1-3: "*During regular irrigation on IID's medium and heavy soils, only 4.5% of the applied water drains vertically, removing about 30% of the salt introduced by the irrigation water, while about 17% ends up as tailwater that removes approximately 22% of the salt introduced by the irrigation water.*" This is an all encompassing statement that is not true. Tailwater contains salts in the irrigation water and salts picked up from the soil. When only the soil salts picked up by tailwater (horizontal leaching) are considered, the salt pickup ranges from 1.3% to 17.5% of the total salts in the delivered water (data collected by IID and calculations found in Table IV-3 (revised) under Comment 10), and from 2.0% to 7.4% of the applied single irrigation event (data collected by NRCE and calculations found in Tables 3 and 4, Appendix 7 (revised) under Comment 24 and summarized in Table IV-4 (revised) under Comment 14). The revised calculations indicate that the effectiveness of salts picked up by tailwater (horizontal leaching) is small compared to deep percolation from the root zone (vertical leaching).

2. Page I-2, para. 6, lines 1-2: "*During regular irrigation on IID's medium and heavy soils, only 4.5% of the applied water drains vertically…*" This statement is in error. The 4.5% vertical drainage in medium and heavy soils is the magnitude found during the monitoring of the irrigation event and does not consider vertical drainage subsequent to the monitored period conveying the salts in the soil into the drains.

3. Page I-2, Para. 7, lines 1-4: *During regular irrigation on IID's medium and heavy soils, only 4.5% of the applied water drains vertically, removing about 30% of the salt introduced by the irrigation water, while about 17% ends up as tailwater that removes approximately 22% of the salt introduced by the irrigation water.*" The statement that tailwater removes approximately 22% of the salts introduced by the irrigation may be true (when salts in irrigation are also included) but this tailwater picks up previously deposited soil salts equivalent to only 5.2% of the total salts in the irrigation event (See Comment 14 for details)

4. Page II-18, para. 3, line 1-2: "*Salinity, pertaining to irrigation water is defined as the total amount of dissolved inorganic ions and molecules*." What are inorganic molecules? Inorganic dissolved mineral salts exist in water as completely dissociated ions and partly dissociated ions known as ion pairs (ASCE, 1990).

5. Page II-20, para. 1, lines 1-7: “

$$LR = \frac{\Delta d}{\Delta a} = \frac{Ca}{Cd} \qquad (II\text{-}1)$$

where:

LR = *Leaching requirement*

Äd =*Required equivalent depth of water passing below the root zone*

Äa =*Equivalent depth of applied water (irrigation plus rainfall)*

Ca = *Weighted-mean salt concentration of the applied water*

Cd =*Required salt concentration of the drainage water”*

The traditional LR is defined by equation (II-2) and not equation (II-1). The ratio $_d$/ $_a$ in equation (II-1) is known as Leaching Fraction (LF). $_a$ is not applied water but infiltrated water and infiltrated rainfall (or effective irrigation and effective rainfall).

6. Page II-20, para. 3, line 4: The ECe term in Equation II-2. ECe is the crop-specific average salinity in the root zone of a given crop above which crop yield is expected to decline. ECe is the electrical conductivity in dS/m of an extract of a saturated soil paste.

7. Page II-21, para 1, line 1: ECiw in equation (II-4) should be divided by 2 in both the denominator and numerator because the reference soil water content differs between ECe and ECiw. ECe was previously defined in Comment 6. ECe is approximately one half the salinity of the same soil at field capacity (ECsw) or one half of ECiw when the irrigation water becomes soil water and then an extract is obtained from a saturated soil paste.

8. Page IV-3, para. 2, line 12: *“… enhance the solubility of soil salts.”* It is not clear how soil cracks can increase the “solubility of soil salts”. When cracks form upon drying, soluble salts from the interior of the soil peds may migrate outwards and accumulate at the exposed crack surface. When the cracks are wetted and filled some of the salts accumulated at the crack surfaces may be entrained in the flowing water and others will diffuse towards the interior of soil peds. The above processes involve salt diffusion outwards and inwards into the soil peds and mineral precipitation and mineral dissolution at the crack surface.

9. Page IV-6, para. 3, lines 4-5: *“They also found that the rooting depth of crops is shallower in heavy soils when compared to light soils. These findings are in agreement with other researchers who studied the soils of IID.”* If plant roots develop more fully in the shallower portion of the root zone, this is a positive rather than negative impact on crop production because the roots are exposed to the least saline shallower portion of the soil (zone of salt leaching) rather than more saline, deeper soils (zone of salt accumulation).

10. Page IV-14, Table IV-3: Tailwater contains salts in the irrigation water and salts picked up from the near soil surface. The % of salts removed by tailwater in Table IV-3 is misleading because it should consider only the salts picked up by tailwater to evaluate the effectiveness of leaching of salts by tailwater. The revised calculations (Table IV-3 (revised), next page) show that % of salts removed by salts picked up by tailwater ranges from 1.3% to 17.5% and not 15% to 58% as indicated by NRCE. The tailwater production from the third silty clay soil is quite excessive, 40.6% of the delivered water, and tailwater salt concentration may be too high.

The salinity in the tailwater hydrograph is known to change from a peak EC to a tailing EC. Is the tailwater salinity in Table IV-2, NRCE, a flow-weighted average salinity or salinity of a grab sample somewhere on the tailwater hydrograph? The calculations in Table IV-3 (revised) assumed that the tailwater salinity is a flow-weighted average salinity.

11. Page IV-15, para. 1, lines 1-7: Based on data presented in Table IV-3 (revised) the 32% quoted should be 9%.

12. Page IV-15, para. 3, line 2: Based on Table IV-3 (revised), the 15% quoted should be 1.5%.

13. Page IV-15, para. 4, line 1: Based on Table IV-3 (revised), the 30% quoted should be 7.8%.

Table IV-3 (Revised) Recalculated tailwater leaching from data collected by IID. (The values in parenthesis were reported by NRCE and the differences are due to rounding off).

	Silty clay	Silty clay	Silty clay	Silty clay/ Silty loam	Sandy loam
Water delivered, ac-ft	3182	5322	3042	2615	2681
Tailwater, ac-ft	677	746	1234	350	567
Tailwater,% of del.	21.3	14.0	40.6	13.4	21.1
TDS del. water, mg/L	618	618	618	618	618
TDS del. water, tons	2674	4473	2557	2198	2253
TDS, tailwater, mg/L	819	852	884	689	657
TDS, tailwater, tons	754	864	1484	327	597
Tailwater TDS, % of del.*	**28.2 (28)**	**19.3 (19)**	**58.0 (58)**	**14.9 (15)**	**22.5 (23)**
TDS, salt pickup, mg/L	201	234	266	71	39
TDS, salt pickup, tons	185	237	446	34	30
Tailwater salt pickup, % of delivered**.	**6.9**	**5.3**	**17.5**	**1.5**	**1.3**

*Ave. = 28.6% (28.6%)
**Ave. = 6.5%

14. Page IV-16, para. 6, Table IV-4: Tailwater salinity consists of salts originally present in the irrigation water and salt pickup from the soil by tailwater. The effectiveness of tailwater salt leaching should consider only salt pickup and not the salts present in the carriage water, too. Thus, tailwater salt pickup is much smaller than salts in the tailwater as indicated in Table IV-4 (Revised). Detailed revised computations are recorded in Comment 24 for Table 4, Appendix 7.

    Evaluating water and salt balance for a single irrigation event in a tile drained field involves inherent difficulties because the flow of tile water during the monitored irrigation event may not truly reflect that irrigation event (because of comparatively slow travel time from infiltration to deep percolation and interception by the tile drain in contrast to overland flow). A substantial portion of the stored soil water is consumed as ET and the remainder contributes to deep percolation out of the root zone subsequent to the monitored period. Since there is a lag time for deeply percolating water to be intercepted by tile drains, a more accurate appraisal would be to continuously monitor tile flow throughout the irrigation season.

    Moreover, tile drainage not only intercepts deep percolation from the root zone but also the shallow ground water (Kaddah and Rhoades, 1976). Silva (1990) reported that the annual salt balance index for IID from 1958-1989 was 1.21, meaning 21% more salts were drained than brought in with irrigation water. This extra source of salts is from the interception of shallow ground water whose salinity is greater than the deep percolation from the root zone (Kaddah and Rhoades, 1976; WAC Report on IID, 2003).

Table IV-4 (revised). Recalculated summary of data for seven fields, data collected by NRCE. (The values in parenthesis were reported by NRCE and the differences are due to rounding off).

	Water balance data		Salt balance data	
	Ave. depth, inches	Average %	Ave. salt load, tons	Average %
Total irrigation	4.37		30.95	
Stored in rootzone*	3.40 (3.43)	77.8 (78.5)	13.91	44.9 (47.9)
Tailwater	0.76 (0.74)	17.4 (17.0)	6.81	22.0 (22.3)
Tilewater**	0.21 (0.20)	4.7 (4.5)	10.24	33.1 (29.8)
Tailwater irrigation			**5.19**	**16.8**
Tailwater salt pickup			**1.62**	**5.2**

*A substantial portion of this is consumed as ET and the remainder contributes towards deep percolation out of the root zone, a fraction of which is intercepted by tile drains.
**Tilewater monitored during the irrigation event may not necessarily represent interception of deep percolation for that irrigation event because of lag time for deep percolation to reach tile drains.

15. Page IV-15, para. 6, lines 4-5: Based on the recalculation in Table IV-4 (revised), leaching by tailwater is not 22.3% (recalculations give 22.0%) of the applied salts but only 5.2% when salt pickup by tailwater is considered. Therefore, tailwater production is not so critical for soil salt leaching.

16. Page IV-16, para.3, lines 5-7: Based on Table IV-4 (revised), the salt load in the tailwater accounts for 40% (6.81/(6.81+10.24))*100) of the salts leaving the field (NRCE reports 43%) but salt pickup by tailwater is only 9.4% (1.62/(1.62+5.19+10.24))*100).

17. Page IV-16, para. 4, lines 1-4: Based on Table IV-4 (revised), the 3.4% reported by NRCE should be 0.7 % ((5.2/33.1)*4.7), the % of headgate delivery used for effective horizontal salt leaching. Therefore, horizontal tailwater salt leaching is not effective when compared to vertical root zone salt leaching.

18. Page IV-19, Figure IV-2: It is notable that about 12 inches of water was used to germinate the sugar beets and about 10 inches of water was used for reclamation leaching at the end of the growing season. If the crop succeeding the sugar beets required a similar germination irrigation there would be no need to practice reclamation leaching after sugar beets. In fact, for many crops and good drainage conditions, it is only necessary to reduce salinity in the top 1.5 to 2 ft depths below the threshold salinity of the crop and not the entire depth of the root zone (Keren and Miyamoto, 1990 in ASCE Manual 71), because root-water extraction pattern for many crops are 40-30-20-10% in the root zone quartiles.

19. Page IV-25, equations IV-3 and IV-4: The difference in LR (not LF as stated by NRCE) is calculated for non-cracking as 11% and for cracking soils as 13%, as an illustrative example. Although the difference in LR may be 20%, the actual difference is so small that one cannot achieve such high degree of precision with typical surface irrigation systems.

20. Page IV-26, para. 3, lines 1-5: The 4.5% quoted for vertical leaching (Table IV-4, revised under Comment 14) is only for the duration of monitoring of the irrigation event. Some of the salts present in the stored soil water are subsequently subject to vertical leaching before the next irrigation event (due to lag time for internal drainage) and the remainder is subject to vertical leaching (44.9%) in the early stages of the next irrigation event. Therefore, the mass of salts leached by vertical leaching is about 78% (33.1% tile drainage + 44.9% subsequent leaching).

21. Page IV-26, para. 5 and 6: The statements made and values quoted are based on lumping together irrigation water salinity and salt pickup from the soil. Since the mass of salts picked up by tailwater is so small (5.2%), it is not prudent to promote tailwater production as a means of salt control.

22. Page IV-27, Table IV-9: The total deep percolation for soils of limited permeability in this table is comprised of deep percolation during crop irrigation and deep percolation during leaching irrigation for annual crops leached every year, equivalent to 8.2 in/yr or

170,000 ac-ft/yr. The basis for the need of leaching irrigation every year for annual crops does not appear to have been established in this report. Since germination water and other agronomic use of water inadvertently leaches salts from the root zone, there is little need for reclamation leaching for annual crops.

23. Page IV-10, Table-10 and Figure IV-3: This table and figure indicate that **of the 17% tailwater production of headgate deliveries, 3.0% is used for leaching heavy soils while 14% is tailwater not used for leaching.** Furthermore, this table points out that **of the 13.5% total leaching water of headgate deliveries, 10.5% is for vertical leaching.** These data as well as Figure IV-3 supports our contention that salt pickup by tailwater (horizontal leaching) is small compared to leaching by deep percolation (vertical leaching).

24. Appendix 7, page 9, Table 4: The data reported in Table 4 was used to calculate salt pickup by tailwater in terms of tons of salt and % tons of salt in the irrigation water (see below the revised calculations). The average from the six fields were reported in Table IV-4, NRCE Report on page IV-16 and revised calculated data in Table IV-4 (revised) in Comment 14 of this critique. Specific comments are given in Comment 14 and will not be re-stated here.

Appendix 7, Table 3 and 4 (Revised). Recalculated detailed water and salt balance during an irrigation event in seven fields, data collected by NRCE (Values on parenthesis are those reported by NRCE in Table IV-4).

Field No.	1	2	3	6	7	8	9	Ave.
Irrigation, ac-ft	22.8	24.8	55.5	32.9	38.6	23.0	21.3	
Tailwater, ac-ft	6.48	3.38	7.15	3.80	7l.3	4.68	3.9	
Tilewater, ac-ft	0.72	0.65	2.60	2.85	1.82	0.96	0.72	
Stored soil water, ac-ft	15.6	20.8	45.8	26.3	29.5	17.4	16.7	
Tailwater, % of irrig.	28.4	13.6	12.9	11.5	18.9	20.3	18.3	17.4 (17.0)
Tilewater, % of irrig.	3.16	2.62	4.68	8.65	4.72	4.16	3.35	4.71 (4.5)
Soilwater, % of irrig	68.40	83.8	82.4	79.8	76.4	75.5	78.4	77.8 (78.5)
TDS, irrig, tons	22.56	24.57	55.49	31.60	37.46	23.26	21.74	
TDS, tailwater, tons	7.44	4.90	11.22	4.29	8.03	6.46	5.30	
TDS, tilewater, tons	3.67	3.25	28.85	13.56	8.19	8.99	5.17	
TDS, soilwater, tons	11.45	16.42	15.42	13.75	21.24	7.81	11.27	
TDS, tailwater, %	**33.0**	**19.9**	**20.2**	**13.6**	**21.4**	**27.8**	**24.4**	**22.0 (22.3)**
TDS, tilewater, %	16.3	13.2	52.0	42.9	21.9	38.6	23.8	33.1 (29.8)
TDS, soilwater, %	50.8	66.8	27.8	43.5	56.7	33.6	51.8	44.9 (47.9)
TDS, tailwater salt pickup,tons	1.04	1.55	4..07	0.65	0.95	1.73	1.33	1.62
TDS, tailwater salt pickup, %	**4.6**	**6.3**	**7.3**	**2.1**	**2.5**	**7.4**	**6.1**	**5.2**

25. Appendix 7, page 10, para. 1, lines 2-3: The statement that up to 67% (Field 2 in Tables 3 and 4 (revised)) of the salts was not removed by either vertical and horizontal leaching is incorrect. Of the water stored in the root zone, a substantial portion is lost as ET and the remainder subsequently contributes toward deep percolation. Vertical leaching as represented by the monitored tile drainage may not represent intercepted deep percolation from this irrigation event because of lag time. Thus, a portion of the salts stored in the root zone eventually will be subject to deep percolation.

26. Appendix 7, page 10, para. 2: As mentioned previously in Comment 20, the salts in the stored soil water are eventually leached out.

27. Appendix 7, page 10, para. 3: Mention of a random sampling of tailwater in cracking soils having salinity up to three times that of the irrigation water is very misleading. In the table of random tailwater data (attached to Appendix 7), only one tailwater sample had an EC of 3.56 dS/m and the average of 33 samples was 1.69 dS/m, about an average 30% increase in EC over that of the supply water.

28. Appendix 7, page 10, para. 6: On extent of vertical leaching, see Comment 20.

29. Appendix 7, page 11, para. 1: This statement is not supported by the ECe maps by soil depths and ECe 4-ft row data presented as attachments to Appendix 7. The highest ECe data in the maximum range of 25 dS/m reported are for Fields 3 and 5 cropped with Bermuda grass. The field notes for both fields indicate the condition of Bermuda grass as "good" and effective rooting depth as 4 ft and 3 ft respectively in Fields 3 and 5. The ECe maps for Field 3 show that the southwest bottom is high from 0 to 3 ft, but in contrast, average profile ECe for 15 rows show a trend of higher salinity in the top end (20-25 dS/m) and lower ECe in the bottom end (5-10 dS/m). The ECe maps for Field 5 indicate the salinity levels are lower than in Field 3 (maximum of about 12-15 dS/m). The 4- ft ECe plots for 7 rows show ECe ranging from 2 to about 10 dS/m except for row 2 with maximum ECe of about 15-25 dS/m midway in the row. In spite of this salinity level the performance of Bermuda grass is rated as good. Bermuda grass is a salt tolerant plant with threshold salinity of 6.9 dS/m.

    In the remaining fields (Fields 1, 2, 4, 6, 7, 8 and 9) the condition of the crops was also rated good. Two of these fields had no ECe data (Fields 2 and 7). The ECe in the remainder of the fields had maximum ECe's in the range of less than 10 to 15 dS/m.

    The tractor-mounted electromagnetic (EM) device used to sense soil salinity gives ECa, EC of the bulk soil or apparent EC, and not ECe (Rhoades et al., 1999). To convert ECa to ECe a calibration curve must be established for each soil type that is affected, among other variables, by relative soil water content of field capacity and percent clay content. The NRCE Report does not indicate how ECe was obtained for the ECe field maps by soil depth and the 4-ft profile ECe along the rows from head to bottom ends.

As mentioned previously most crops have a 40-30-20-10 root-water extraction pattern and the effective rooting depths for the crops in these fields are reported to be 4 ft, so that about 70% of water extraction occurs in the top 2 ft of the soil where salinity is typically lowest and is in the zone of where cracks occur in clayey soils. The performance of the crops at the time of the irrigation event was rated "good" for all crops in the nine fields.

One reaches the conclusion that root zone salinity is adequately controlled by vertical leaching during crop irrigation and germination irrigation, and horizontal leaching by tailwater plays a minor role. The need for tailwater production to sustain crop production in IID has not been documented by NRCE.

B. Comments on Declarations of Dr. Mesghinna, NRCE, in reply to opposition by federal defendents to IID's motion for preliminary injunction, dated March 18, 2003 by Dr. Kenneth K. Tanji.

30. Page 8, lines 6-10: A point is made that only a portion of the salts in the soil are leached during regular irrigation and additional leaching between crops are required. This point is refuted by Comments 14, 18, 20, 22, 25, and 29.

31. Page 8, lines 17-22: Water lost through deep percolation in CVWD contributes toward recharging an over drafted ground water basin and later may be pumped for future use while water lost through tailwater in IID goes to the Salton Sea and is irrecoverably lost in a salt sink

32. Page 8, lines 27-28: This statement is false. Re-calculated data in Table IV-3 (revised) under Comment 10 indicates that tailwater salt pickup averaged 6.5% of salt load in the delivered water for five fields monitored by IID and in Table IV-4 (revised) under Comment 14 tailwater salt pickup averaged 5.2% of delivered salt load in seven fields monitored by NRCE.

33. Page 9, lines 1-6: The data quoted are erroneous. Comment 20 pointed out that the 4.5% quoted for vertical leaching is only for the duration of monitoring during the irrigation event and that vertical leaching is of larger percentage. Comment 20 also pointed out that the mass of salts vertically leached averages about 78% of the salt load in the irrigation water with an average 17% tailwater production, as monitored by NRCE.

34. Page 9, lines 20-23: This statement appears to be logical but the profile ECe in the rows of monitored fields by NRCE, attached to Appendix 7, show that of the 72 rows (lanes) 27 rows had lower ECe in the bottom end while 10 rows had little or no gradient in ECe from head to bottom ends. **Therefore, about one half of the rows monitored by NRCE did not exhibit increased soil salinity at the bottom end as compared to the top end of the fields, and they do not require additional leaching.**

35. Page 9, line 28: The 0.73 ac-ft/ac leaching water includes 0.48 ac-ft/ac of leaching irrigation of annual crops (Table IV-9) in addition to deep percolation leaching during crop irrigation of annual crops grown in soils of limited permeability. Since annual crops require germination (and seedbed) irrigation, it is questionable that annual reclamation leaching is necessary (see Comment 18).

36. Page 10, lines 8-9: **It is not reasonable and beneficial to produce excess tailwater for horizontal salt leaching when the salt pickup from the soil in IID's field study averaged only 6.5% of delivered irrigation water (Table IV-3 (revised)) and NRCE's field study averaged only 5.2% of delivered irrigation water (Table IV-4 (revised).**

C. Comments on NRCE's Report on Assessment of Imperial Irrigation District's Water Use, dated March 2002 by Dr. Wesley W. Wallender

1. Pages I2-I3. See comments on conveyance and distribution efficiency and tailwater, etc. below **(**Comments on Declarations of Dr. Mesghinna).

2. Page II-4, para2. Reliance on a single water supply a distance away is not an unusually difficult condition.

3. Page II-11. The growers should <u>not</u> be charged for a full 12 hr run if they reduce or remove the order prior to the full twelve hour period. With the flexibility of two hours of advance notice to either terminate or reduce flow, the growers can irrigate such that tailwater is reduced to near zero.

4. Page II-16, para2. It is not true that if the inflow is terminated when the water arrives at the field end that the lower portion of the field would be short of water. Water stored on the surface during the advance phase moves from the upstream locations, where the infiltration rate is zero or near zero, to the downstream end of the field. There the water meets or exceeds the amount of water that can infiltrate at the downstream end before the infiltration rate also falls to near zero. Salt, that is picked up during advance, unavoidably infiltrates at the downstream end. During the runoff phase, at the downstream end, later arriving surface water of higher quality may mix with the higher salinity water deposited in the cracks when the advance front arrived (earlier). This mixing, which may occur before the cracks swell shut, might reduce soil salinity but only slightly. In general, however, stored water on the surface during the advance phase, in excess of water that infiltrates at the downstream end, is wasted.

5. Page II-16, para3. Varying intake opportunity time does not result in different amounts of water entering the soil (WAC 2003). Crop loss from standing water can be avoided by terminating inflow to prevent runoff and standing water at the downstream end.

6. Page II-16, last para. Salinity at the tail end of the field can be managed by reclamation leaching. Managing ponding time, during seasonal irrigations, for the lowest infiltration

rate region of a field does little to homogenize infiltration due to the cracking nature of the soils (see previous comment).

7. Page II-17, para2. Evaporation is driven predominately by the level of incoming radiation. No quantitative evidence is give to support the claims that evaporation is enhance by vapor and heat transfer, nor by increased surface area.

8. Page II-17, -18. Water used for purposes presented on these pages is not additive. For example water used for germination also serves to leach soil salts.

9. Page IV-7, para3-4. Although each sentence is clear, the unique nature of cracking clay soils is clouded. Again, intake opportunity time or ponding time variability does not strongly influence the uniformity of water application in surface irrigation of cracking clay soils but it may in non-cracking soils.

10. Page IV-8, para1. No measurements are reported to justify the statement that most water flow is by lateral transmission below the soil surface rather than overland. The statement that "lateral movement will provide the only means of leaching" is not based on measurement or reason. Granted, salt stored on the soil ped surfaces can be entrained in the water flowing on the surface and be convected downstream with the flowing water. However, as the advancing front of water moves downstream it fills the cracks and infiltrates into the soil peds, depositing its salt. Thus the movement of salt in the flowing water is stepwise (pickup and deposit) along the field. After the cracks close the concentration of surface flow upstream of the cracks is approximately that of the inflow to the field because surface salt is no longer available for entrainment. Furthermore, after the advancing front passes, there is virtually no physical process for the soil water salt to be transported, on average, to the field end. On the contrary, if the salt concentration is higher at the downstream end, then the salt should diffuse upstream rather than downstream from the time the cracks swell shut until the next irrigation event.

11. Page IV-8, lastpara. There is not direct evidence reported that a "large" portion of water flows horizontally below the surface. In any case once the cracks fill at the field end, this conjectured process of volume-average horizontal convection of water and salt below the soil surface would largely cease. After the cracks close the concentration of surface flow upstream of the field end is approximately that of the inflow to the field because surface soil salt is no longer available for entrainment. Flow off the field is wasted.

12. Page IV-10, para4. To accurately evaluate if a very small amount of runoff is justified to pick up salt measurements of runoff water concentration and flow rate as a function of time are needed (see below).

13. Page IV-11, item8. Without measurements of surface water concentration along the advancing water stream with time, one can not claim that the quality of irrigation water declines with distance down the field.

14. Page IV-11, item12. Without measurements one can not claim that more water is needed to leach cracking clay soils.

15. Page IV-12, item13. These statements are related to management. Cracking clay soils require different management compared to non-cracking soils. It is conjecture to say one is more difficult than the other.

16. Page IV-12, item15. After the cracks swell shut, not after the crack fills, the infiltration rate drops to a very low to near zero value, because the surface area for infiltration declines to the field area covered with water.

17. Page IV-12, item17. The claim that substantial amounts of salt are removed by tailwater is undocumented and misleading (see analysis below). Furthermore the term substantial is vague.

18. Page IV-12, second to last para. The justification for tailwater is not documented.

19. Page IV-12, last para. Tailwater for cracking and non-cracking soils is not justified. With proper water management tailwater can and should be prevented because it is a waste.

20. Page IV-13. The water infiltration profiles in the Figure are incorrect and misleading. Random variation is absent and in the case of cracking clay soils there should not be a trend of decreasing infiltration with distance down the field, rather the average infiltration is constant along the field.

21. Page IV-14 and I-15. This presentation on tailwater studies is misleading because it is based on the amount of salt removed from the total inflow water rather than the amount of salt removed from the soil. For example if there was no salt pickup from soil surface, and 17% of the water ran off the field than 17% of the salt applied to the field would be removed by tailwater. However, this process does not remove salt from the soil system and hence is neither reasonable nor beneficial.

    A rational salt balance approach follows in which the salt pick up from the soil as well as vertical salt leaching from the soil are calculated assuming the reported concentrations were volume weighted (see next paragraph). The difference in concentration between irrigation and runoff multiplied by the volume of runoff gives the 185 tons of salt picked up by the irrigation water for the silty clay example found in Table IV2 and Table IV3 (k (819-618) 677 in which k is unit conversion factor). During the same irrigation event 2104 tons of salt are deposited in the root zone via infiltrated irrigation water. The calculation is made using a surface water salt budget as inflow minus surface outflow minus pickup which is change in storage (3182(618) k – 677(819) k - (-185)). Some of the deposited salt leaches below the root zone during and shortly after the irrigation event and the remainder migrates to the soil surface and is available for pickup (185 tons) during the next irrigation event. Next a soil salt mass balance is used to calculated vertical leaching. The mass of salt that is deposited during irrigation infiltration minus that which is picked up during the next irrigation is the 1919 tons of salt that moves vertically below the root zone (2104 - 185) to sustain a salt balance, no change in storage (Column 6 of Table IV3). Of the total soil salt deposited by irrigation water (2104), only 9% is removed by pickup while the remaining 91% is removed by vertical leaching. Thus 21% of applied water is used to remove 9% of the soil salt where as the remaining 79% of applied water meets both the ET demand and the leaching of 91% of the soil salts originating from irrigation water. As shown in the table below, surface pick up is an inefficient use of irrigation water for removing salt from the soil, regardless of soil type.

Soil	Irrigation Flow, acft	Irrigation Conc., mg/L	Tailwater Flow, acft	Tailwater %	Tailwater Conc., mg/L	Pickup ton/acft	Vertical Leach ton/acft	Pickup %	Vertical Leach %
Silty Clay	3,182	618	677	21	819	185	1,919	9	91
Silty Clay	5,322	618	746	14	852	237	3,605	6	94
Silty Clay	3,042	618	1,234	41	884	446	1,072	29	71
Silty Clay/Silty l	2,615	618	350	13	689	34	1,868	2	98
Sandy Loam	2,681	618	567	21	657	30	1,745	2	98

k is a unit conversion
0.00135874

In this analysis we have assumed, as have the authors, that the reported concentration in the tailwater and deep percolation are volume weighted. Runoff concentration could be determined by collecting all the runoff in a container, mixing it perfectly and measuring sample concentration. Alternatively volume weighted runoff concentration is calculated as runoff flow rate multiplied by concentration and the time interval and then added over all the time intervals of the runoff event, and finally divided by the total runoff volume. Unfortunately, the authors did not report how they measured or calculated the average volume weighted concentration. We assumed the concentration was volume weighted. If the concentrations reported by the authors are from a water samples taken at the beginning of the runoff phase, when the concentrations are highest, the calculations of % pick up reported in the table above as well as Table IV3 are higher than actual and the justification of pick up is further weakened.

22. Page IV-16, para3. By calculating the 3.4% of headgate delivery for beneficial horizontal leaching using the author's method (percent of salt applied and removed by tilewater multiplied by (percent of salt removed by tilewater/percent of salt removed by deep percolation)), the authors assume that the horizontal and vertical leaching process are the same. This is not justified. The difference in tailwater 17%-3.4% = 13.6% "provides adequate irrigation and significantly benefits the crop" according to the authors but neither adequate nor benefit is defined.

23. Page IV-19. The germination irrigation illustrated in Fig. IV-2 should serve the dual purpose of reclamation leaching and germination. Without the reclamation leaching, the initial near surface salinity prior to germination irrigation would be excessive. However, during the germination irrigation, the near soil surface is reclaimed early in the process and the desired soil water condition is achieved. The reclamation leaching is wasteful

because for the same amount of water passing through the soil profile the soil salinity decrease shown in the Figure could be achieved during the germination irrigation.

24. Page IV-20, para1. Tailwater pick up of salt is wasteful.

25. Page IV-20, para3. Tailwater can be controlled by adjusting the inflow rate and time of cutoff.

26. Page IV-20, para4. As in the case of non-cracking soils, vertical leaching is the dominant means of soil salt removal for cracking soils. Pick up of soil salt and its convection in the overland flow is unavoidable but tailwater has been shown above to be wasteful.

27. Page IV-23, para3. Tailwater for pick up of soil salt and its convection in the overland flow has been shown above to be wasteful. Elevated salt concentrations with depth are most likely related to upward movement of water from the shallow water table to meet ET demand between irrigations. Salts are transported upward and deposited in these deeper layers.

28. Page IV-24, para1. A major difference between pick up and vertical leaching is that the concentration of tilewater is much greater than tailwater thus showing that vertical leaching is much more effective and than is pick up of salt. Not only does the vertically moving water transport salt, it also meets the crop ET demand.

29. Page IV-24, para2. Although the leaching <u>requirement</u> is a function of irrigation water quality, there is no control over the leaching <u>fraction</u> during seasonal irrigations because infiltration is controlled by the soil not by intake opportunity time. This is not the case for reclamation leaching and thus the amount of reclamation leaching should increase with distance from the inlet.

30. Page IV-24, para4. The authors acknowledge that increased intake opportunity time during seasonal irrigations does not increase leaching. This contradicts their earlier statements that tailwater is effective for leaching because intake opportunity time is extended during the runoff phase.

31. Page IV-Equations3-4. Leaching fraction LF is incorrectly used; it should be LR for leaching requirement. These equations are the same form as Equation IV-4 and the authors are actually suggesting that the leaching <u>process</u> is the same as in a non-cracking soil. The only adjustment is in the infiltration water concentration which are not reported.

32. Page IV-26, para1. Based on the previous statement the authors <u>are</u> using Rhoades equation without adjustment for process, a contradiction in what is said.

33. Page IV-26, para2. The 22% removal by pick up is not based on soil salt removal but is based on total salt in the inflow, yet the equations suggested to estimate salt removal are

based on soil salt removal. The authors are incorrectly using two different physical systems and processes.

34. Page IV-26, para3. Because tailwater runoff is included in the analysis, the fraction of water going to vertical leaching is artificially driven down to 4.5%. If one uses the fraction of infiltrated water into the soil rather than the fraction of applied water, the fraction of water for vertical leaching increases. Again, one should not use the applied irrigation water salt as the reference when tailwater is included.

35. Page IV-26, para5-6. Again, one should not use the applied irrigation water salt as the reference when tailwater is included. Tailwater pick up is not justified.

36. Page IV-27. The analysis gives no justification for the 17% tailwater loss.

37. Page IV-29 and IV-30. The analysis gives no justification for the 13% tailwater loss.

38. Page V-27 and V-28. Beneficial uses are included in the analysis of irrigation project water budgets, the situation in IID is not unique. What is special about IID is the cracking clay soils and their predictable ease of surface irrigation to avoid tailwater. The pickup and deposition of salt from the upstream end to the downstream end apparently causes a salinity gradient in the field which can be managed between cropping seasons via routine germination/reclamation leaching. Another special characteristic of IID is that the water lost at the farm scale travels to irrecoverable sinks consisting of the saline groundwater system and the Salton Sea. In contrast to other water and irrigation districts, where losses at the farm scale are recovered and the water is reused, that is not the case in IID. As a consequence the "ratio of water beneficially used to irrigation water available does not increase with space scale in IID whereas it does in other districts.

39. Appendix7, Page 3, para4. The amount of salt added in irrigation water is <u>not</u> typically equal to the salt in drainage. Drainage is a blend of deep percolation water and regional groundwater.

40. Appendix7, Page 10, para3. A significant fraction of soil salt is <u>not</u> removed by the pick up process.

41. Appendix7, Page 10, para5. Here it is acknowledged that tailwater concentration decreases with time. After the cracks swell shut and infiltration rate drops to near zero, the tailwater concentration approaches that of the irrigation water.

42. Appendix7, Page 6, para5. Because the advance rate is nearly linear (Appendix7, Page 4, para1) than the infiltration rates must fall to near zero and hence the "intake rate after initial infiltration" in Table 2 are misleading because they occur over a very short time between cracking filling and the crack closing (Appendix7, Page 3, para7, Appendix7, Page 7, bullet3).

43. Appendix7, Page 8, para5. The use of average infiltration rates disguises the opportunity for improved understanding and improved irrigation management such as terminating flow to reduce or prevent tailwater.

44. Appendix7, Page 9, bullet3. If runoff can be controlled on “light soils” there is no reason that it can not be controlled on “cracking clay soils”.

45. Appendix 7, Page 9, Table 4. As noted above the method to calculate salt removal by tailwater is misleading. Furthermore assuming that tilewater concentration is directly related to deep percolation water is dangerous because tilewater is a mix of regional groundwater and deep percolation.

46. Appendix7, Page 11, Bullet4. If IID Regulation Number 4 is enforced to control tailwater during reclamation leaching, tailwater should also be controlled during all other irrigations.

D. Comments on statement of expert qualification and written testimony of Dr. Woldezion Mesghinna in support of IID-SDWA joint long-term transfer petition. Imperial Irrigation District and San Diego County Water Authority, Petitioners. March 21, 2002 by Dr. Wesley W. Wallender

1. Page 5, line 7-11. 83% application efficiency is incorrect (WAC 2003). 74% overall efficiency is incorrect (see our report).

2. Page 6, line 1. Farming in hot climate with clay cracking soils is not justification for water waste or loss. Cracking clay soils are easier to irrigate efficiently because varying intake opportunity time does not affect uniformity.

3. Page 6, line 8-9. The 89% conveyance efficiency is not high considering that all the losses due to seepage and spillage are lost to salt water sinks including the groundwater and the Salton Sea.

4. Page 6, line 12. Tailwater is not a vital and necessary component to Imperial Valley irrigation. It is possible to vertically leach the soil with little to no horizontal leaching.

5. Page 7, line 7. It is not stated when the concentration was measured during the runoff event. The concentration declines with time after runoff begins. The 30% increase in concentration “may” refer to the volume weighted concentration but it is unknown from the document how this percent increase was calcuated.

6. Page 7, line 12-13. More than 4.5% of the applied water drains vertically and it removes more than 30% of the soil salt (WAC 2003).

7. Page 7, line 17-19. At least 17% of applied water is tailwater and much less than 22% of soil salt is removed via tailwater (see Dr. Tanji’s analysis, above).

8. Page 8, line 1. Growers apply more water than for crop use and “partial leaching” because if they did not, the District would have high root zone salinity and no economic crop production.

9. Page 8, line 13-16. Lumping reclamation, seasonal and horizontal leaching suggests that horizontal leaching is a beneficial use. It is not. The difference between the 0.73 and 0.58 acre feet per acre when comparing cracking clay with sandy soil is presumably caused by pick up of salt in the case of cracking soils, but this is not justified.

10. Page 8, line 16. “Limited permeability” is unclear.

11. Page 8, line 19. Irrigation water use in IID is not fully reasonable nor beneficial.

12. Page 9, line 20. Size and distribution system efficiency need not be inversely correlated as suggested. Proper management leads to high performance.

13. Page 10, line 21. It is not conventional to use the water balance approach to determine comsumptive use.

14. Page 11, line 14-16. No justification for a higher than “traditional” leaching requirement for cracking clay soils is given (see Dr. Tanji’s analysis, above).

15. Page 15, line 4-8. Not mention is made of a farm water conservation program, such as source control, other than land leveling.

16. Page 16, line 6. These water conservation measures are generally cost effective and are suited to most soils, parcels and crops in IID (WAC 2003).

17. Page 17-18. There is no mention of source control water conservation measures such as controlling the cutoff time to reduce tailwater.

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VII. ACRONYMS PREPARED BY THE WAC FOR THE COACHELLA VALLEY WATER DISTRICT

TERM	ACRONYM
CALFED	California Water Policy Council and Federal Ecosystem Directorate
CCUnet	Net Crop Consumptive Use
CIMIS	California Irrigation Management Information Systems
CUnet	Net Consumptive Use
CVWD	Coachella Valley Water District
d	Flow Depth
Dcet	Unit Depth of Seasonal Crop Evapotranspiration
Deci	Unit Depth of Seasonal Effective Crop Irrigation
DWR	California Department of Water Resources
EC	Electrical Conductivity
ECe	Electrical Conductivity of Saturated Soil
ECiw	Electrical Conductivity of the Applied Irrigation Water
ECq	Electrical Conductivity of the qth Quartile
ECw	Electrical Conductivity of the Water Applied
Epan	Class A Pan Evaporation
ET	Evapotranspiration
ETc	Crop Evapotranspiration
ETo	Grass Reference Crop Evapotranspiration
ETp	Alfalfa Reference Crop Evapotranspiration
ETr	Reference Crop Evapotranspiration
IBI	Ion Balance Index
ICCUR	Irrigation Crop Consumptive Use Ratio
ICUR	Irrigation Consumptive use Ratio
IID	Imperial Irrigation District
IOT	Intake Opportunity Time
IRdiv	Irrigation Delivery
Kc	Crop Coefficient
Kpan	Monthly Pan Coefficient
L	Border Length
LF	Leaching Fraction
LFq	Leaching Fraction of the qth Quartile
LR	Leaching Requirement
LRvol	Leaching Requirement Volume
M & I	Municipal and Industrial

LIST OF ACRONYMS (Cont)

TERM	ACRONYM
MAF	Million Acre Feet
MWD	Metropolitan Water District of Southern California
NWS	National Weather Service
Pe	Effective Precipitation
q	quartile
Q	Inflow Rate Per Unit Width of Border
SB	Salt Balance
SBI	Salt Balance Index
SDCWA	San Diego County Water Authority
SS	Salton Sea
SWRCB	State Water Resource Control Board
T	Irrigation Time
Tco	Cutoff Time
TDS	Total Dissolved Solids
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
WAC	Water Advisory Committee
WB	Water Balance
WBI	Water Balance Index
Wq	Extraction Pattern in the Rootzone Quartile
WST	Water Study Team
X	Advance Distance at Irrigation Time T along the Border
z	Infiltration Depth